New World of Machines

RESEARCH DISCOVERY INVENTION

BY HARLAND MANCHESTER

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WHEN an obscure research chemist tampers with a molecule no bigger than a billionth of a pin-point, the results may shake the earth. When a curious physicist fiddles with the gadgets in an electronic tube, the future of man and all his institutions may be altered forever. Convinced that some of the most important forces in the history of civilization were being quietly marshalled behind the doors of laboratories and factories, Harland Manchester, seasoned newspaperman and magazine writer, set out several years ago on a quest which has led him through the lairs of the modern alchemists of American industry—the men who are shaping the breath-taking world of tomorrow. Exploring giant production plants and busy laboratories throughout the country, he has observed at first hand the fabulous machines and processes of the new machine age, and has interviewed hundreds of America's leaders in production, scientific research and engineering.

In a vivid, dramatic style and non-technical language, Harland Manchester describes radar, television and new wonders of lighting and communication; developments in transportation—the Diesel engine, high-octane gas, the turbosupercharger, the helicopter; artificial rubber, plastics and other new materials; novel techniques in farming; and many other of the discoveries and inventions which will revolutionize our lives within the next few years.

Mr. Manchester is a native of New England, a graduate of Dartmouth College, an ex-Marine and a former Boston newspaperman. He now lives in New York, and is a roving editor of *The Reader's Digest*, in which his articles frequently appear.

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NEW WORLD OF MACHINES

RESEARCH
DISCOVERY—INVENTION

By *Harland Manchester*

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THIS IS A WARTIME BOOK

The text is complete and unabridged

but every effort has been made to comply with

the Government's request to conserve essential materials

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TO LAETITIA, STEPHEN AND SUSAN

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"Chemical rubber trees."

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PREFACE

THE MAKING OF MANY MACHINES has long been a proclivity of Earth's major primate. Year by year these machines have become more ingenious and complicated, and man has regarded with increasing awe the giants which he has set in motion. Because he frequently misunderstands their potentialities, these mindless behemoths sometimes knock him down, trap him in their gear-wheels, and even appear to compete with him for bread. And because of their cumulative complexity, they tend to dwarf and shrivel their creator, who sometimes forgets that they are his servants, and endows them with will and intention which they do not possess.

If "the machine age" has brought its problems in the past, it will bring more and greater ones in the immediate future. The machines of yesterday are crude and simple compared to those which are now entering service, and which will soon play an amazing role in doing the work of the world.

We are on the threshold of the greatest technological advance since the development of the internal combustion engine. A flood of discoveries and inventions, first dammed up by the world depression, then devoted mainly to war uses, will be released as soon as the arts of peace are resumed, and man must prepare himself for its impact upon all the conditions of his life.

Vastly improved methods of communication and transportation have already destroyed our notions of distance and will shatter what may be left of the old comfortable feeling of inaccessibility. Today, no spot on earth need be more than sixty hours away, and this time-barrier will soon be lowered. A little glass tube devised forty years ago has at last made possible the extension of our sight and hearing to the world's remotest place. Chemists have altered the molecules of an earth liquid, once wasted, to produce a new miracle of power. From earth, air and water they have synthesized a useful and pleasing variety of structural materials and fabrics. Engineers have invented new motors to carry man's loads and still further reduce his labor on factory and farm. They have cleverly applied this power to a thousand tasks so that one man's useful output is tremendously increased.

Meanwhile, our dependence upon these fabulous new tools and processes, which may nurture us or destroy us, according to their employment, increases in inverse ratio to our comprehension of them. These things will set the pace for the lives of all the people, and they will be paid for from the incomes of all the people. It is the clear duty of all the people to acquaint themselves with the machines which must inevitably affect their future and that of their children. It is the purpose of this book to promote, to some small degree, such an acquaintance.

The author owes a heavy debt to many persons and organizations who have assisted him with information or encouragement. First of all, he thanks the editors of *The Reader's Digest*, *Harper's Magazine* and *The Atlantic Monthly* for their early interest in his articles dealing with technical matters, and for permission to use material from those articles in preparing this book. For similar permission he thanks the editors of *Science News Letter*, *U. S. Camera*, *The Toronto Star Weekly*, *Forbes Magazine* and *American Forests*.

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H. M.

PART ONE

TAMING THE SPECTRUM

CHAPTER ONE

THE MIGHTY ELECTRON

On the night of November 14, 1942, it was black as pitch in the Solomon Islands and the rain was pelting down with tropical generosity. An American warship rode off Guadalcanal. In an insulated, sound-proofed compartment, super-heated with electrical equipment, two men fiddled with controls. Lookout men aloft could hardly see their hands before their faces, but these men had magic eyes. They made a sudden discovery—no matter exactly how. They phoned the bridge, guns were elevated, and a salvo rocked the ship. With the second salvo, a Japanese battleship, eight miles away through the blackness, shuddered from a blow to her vitals and began the slow, angular glide to oblivion.

Radar, the war's greatest new weapon, had done its work. This was the incredible device which defeated Goering's bombers in the Battle of Britain. Had the RAF been unable to foresee each blow of the then mighty Luftwaffe—had they been forced to disperse their fighter planes to meet attacks from any direction, instead of holding them in a central position to repel each assault—the swastika might now fly over London.

At the heart of radar is a group of electronic tubes—light bulbs with university degrees. They are members of a growing family of more than 700 tubes which in a few short years have been harnessed to an amazing variety of tasks. In the Battle of the Mediterranean, for example, an aerial observer spotted enemy troops in the act of preparing an ambush. He swiftly sketched the position on a map and put the sheet in a facsimile transmitter—another electronic device. A few minutes later, at an American base hundreds of miles away, an officer pulled a duplicate of the map off a receiving machine, and the field commander was promptly warned of the trap. A few electronic tubes saved an entire company.

This versatile tube, which has no moving parts and does its work invisibly, is easily the greatest technical marvel of the twentieth century. It ranks in importance with Faraday's discoveries in electricity or the development of the internal combustion engine. In a few short years it has become an indispensable tool in communications, amusement, transportation, industry and medicine. It is the cornerstone of radio and television; it is the voice of motion pictures, and without it, the modern telephone network would collapse. As the X-ray it saves lives by the million and swiftly probes machine parts for flaws that the human eye cannot see; as the electron microscope, it has extended our vision into the infinitesimal and may soon make a public exhibit of the elusive molecule. As the electric eye, it opens doors, catches thieves, detects fires, sorts beans and counts automobiles. In industry, it speeds production, saving man-hours and costs, and insures greater precision and higher quality. It tempers metals, bonds plywood, "sews" sheet aluminum and plastics, dehydrates food, sterilizes air. And this is only the beginning. In the laboratory, it has broadcast power through the air to light electric lamps, and has baked a loaf of bread in three minutes.

These tubes vary in size all the way from a thimble to a hogshead. Some are as simple and symmetrical as the one in your midget radio; others have sprouted weird, futuristic protuberances, and have innards cluttered with multiple gadgets which shape them for specialized jobs. Some are sold for fifty cents; others cost hundreds of dollars.

Whatever the size or shape, all electronic tubes depend upon the same basic principle: when metal is heated, or when light falls upon it, it spits out electrons. And whether the tube closes a door, sees a plane many miles away, or converts a great stream of electrical power into a form that will drive machines, it does its work by liberating electrons within the tube and controlling their behavior.

The electron is one of the smallest particles known to science, and belongs in the mystic sub-minuscule realm where matter and energy meet. Figures tend to lose their meaning when applied to its size, but physicists estimate that it would take thirty billion billion billion electrons to weigh an ounce, and that when you read beneath a 100-watt lamp, six million trillion of the particles race through the filament every second.

The liberators

Imprisoned in closed circuits, these speeding electrons have been serving man for many years. It was not until they were liberated that the science of electronics began. Back in the 1880's, two men, working independently, found keys to their dungeons. Thomas A. Edison made an epochal discovery which proved that heat would pry them loose from their parent atoms. Neither Edison nor anyone else understood this so-called "Edison effect," and he proceeded with his work on the electric-light bulb, in which the electrons do their work in closed circuits.

Light falling upon metal was the key of Heinrich Hertz. Hertz' discovery, called the "photoelectric effect," led to the development of the electric eye, known to industry as the phototube. This is the oldest and the simplest of all the electronic tubes, and its behavior is easiest to comprehend. It has been used in laboratories for more than forty years, but the public got its first good look at it in the middle thirties when it was introduced as an automatic door-opener. They saw two metal posts about five feet apart, each with a small, round window the size of a baseball. Between these windows streamed a horizontal beam of light—an intangible barrier about three feet from the ground. When the body severed the light beam, the door swung open, remained open for a suitable time, then slowly closed. This was perhaps the simplest of the many jobs the phototube has been taught to perform. The beam of light, which comes from an ordinary light bulb, falls upon the phototube, and this light-sensitive cell translates the interruption of the beam into electrical energy, which, when amplified, starts a motor which does the work.

Young Heinrich Hertz had no such idea in mind in 1887 when he stumbled upon this revolutionary principle. His discovery of the "photoelectric effect," a phrase which may be more simply stated as "the effect of light upon electricity," was only an unexpected incident of his experiments with wireless waves. He was watching a device containing two spark gaps, and observed a tiny discharge of energy across one of the gaps which all his experience told him had no business there.

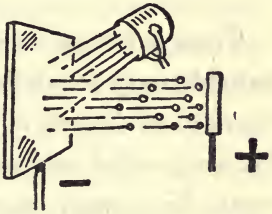
"I had no intention of allowing this phenomenon to distract my attention from the main object I had in view," he wrote, "but it occurred in such a definite and perplexing way that I could not altogether neglect it."

In searching for the cause of this discharge, Hertz finally ruled out everything but the invisible ultra-violet light which came from the other spark gap of his apparatus. He was forced to the conclusion that the light had knocked a little stream of energy out of the zinc conductor. Why this happened he did not know, and with some relief he recorded the results of his detour and returned to his real work.

It doesn't matter that Hertz used zinc, or that the light was ultraviolet. What he had accidentally encountered was the fact that when light falls upon metals, it makes them emit electrons. We may say that light—or heat, as Edison discovered—"boils" electrons out of metal.

But Hertz had never heard of an electron—no one had in 1887. Before anyone could find out what really happened that day in Hertz' laboratory, the old conception of the atom—that it was the final, indivisible building block of all matter—had to be demolished. It took daring physicists like Sir J. J. Thomson to demonstrate that the atom is a kind of little solar system; that it has an electrically positive nucleus in the middle, and that around this nucleus swims a school of negatively charged particles called electrons, which dash around their orbits with the speed of light and are loosely held to the parent atom by the attraction of the positive nucleus.

Hertz' light, falling upon the piece of zinc, had broken the electrical bonds which held the electrons in place, and had knocked a procession of them out of their orbits. They had to go somewhere, and since they were negatively charged, they were attracted by the positive conductor of Hertz' apparatus. They leaped across the gap and set up the little stream of energy which he observed.



How the phototube works —light falling on metal makes it emit negative electrons, which are attracted by positive electrode, setting up current. (Courtesy General Electric Co.)

Within a few years after Hertz' discovery, other men built its principles into the photoelectric cell, which has not changed essentially since that time. Simply described, it is a glass bulb which looks like a light bulb, part of which is lined inside with potassium, a silver-colored material. A wire connects this lining with a battery, and another wire from the battery is connected with an upright terminal in the middle of the bulb. Thus we have a circle broken by the gap between the silver-colored lining and the positive electrode. The potassium is very sensitive to light. Put this bulb in a dark room and nothing happens. The negatively charged electrons in the atoms of potassium swim contentedly in their orbits. But if you turn a flashlight on the bulb, the electrons leave home in droves. Lured by the positive terminal in the middle, they jump madly across the gap, completing the circuit. If you connect a meter to one of the wires outside the bulb, it will show you that a tiny current is flowing. The stronger your light, the stronger the current will be. Cup your hand over the light, and the current will stop instantly. Flash the light in some sort of code, and the meter shows you that the current is copying it.

Described in terms of practical use, the photoelectric cell is a gadget that will enable light impulses to govern mechanical operations, and that will translate light variations into corresponding variations of energy—all this with speed and accuracy which tax human powers of comprehension.

Harnessing the electric eye

These practical uses were retarded for many years, for the cell was suitable only for delicate laboratory tasks. Scientists had penetrated the dark wilderness of the atom and returned with a revolutionary tool, but they could not harness it to workaday jobs. The current was too weak. Its strength was only about one ten-millionth of what it takes to light an ordinary household bulb.

The first electronic tube soon hoisted itself by its own bootstraps. A procession of distinguished experimenters, including Fleming, De Forest, Langmuir and Armstrong, using Edison's discovery of boiling out the electrons by heat, introduced new parts in the bulb, and made it into an amplifying tube that would supplement the phototube by building its weak current up to working size.

The first commercial job of the phototube was in 1924, when Bell Telephone Laboratories reached a goal toward which inventors had been plodding for half a century—the transmission of pictures over a wire. It was Dr. Herbert Eugene Ives, the firm's director of electro-optical research, who negotiated the wedding between the two tubes, multiplying the phototube's current a few million times so that it was strong enough to perform a useful function.

The union bore issue in June that year, when news photographs taken at the Republican convention at Cleveland were sent over the wire to New York. The picture to be transmitted was wrapped around a cylinder, which revolved in a lightproof metal case. A carriage bearing the phototube and a thin pencil of light slowly traveled the length of the cylinder, like the needle of an old-fashioned phonograph record. The light beam thus performed a long, tight spiral around the cylinder. The phototube scanned the narrow, illuminated band of the photograph, and its sensitive electronic current varied in strength with the lights and shades of the picture. Bolstered by the amplifying tubes, this varying current went over the wire to the New York office. It could actually be heard by those present in the form of a hoarse, vibrating scream. In the receiving machine, the current hit a metal ribbon which concealed a light beam. The impact of the current made the ribbon shimmy from side to side, emitting a varying stream of light which copied faithfully the degrees of light and shade seen by the phototube in Cleveland. The pencil of light fell upon a photographic film wrapped around a revolving cylinder, and thus built up, line by line, a reproduction of the original photograph. The pictures were coarse-grained and the backgrounds were blurred, but the next morning, newspaper readers gazed upon an indubitable representation of a group of political ladies posing with elephants in front of Coolidge headquarters. Soon the word "telephoto" entered the language.

Once the first practical phototube was developed, engineers and manufacturers were quick to perceive the many uses to which it could be adapted. Used in conjunction with other electronic tubes, it was taught to simulate seeing, hearing, talking, feeling and even smelling. Since it reacts to its stimulus of light within a thousandth of a second, and detects variations of light and color far beyond the power of the human eye, it has replaced men in hundreds of delicate tasks and has set new standards of swiftness and accuracy.

Rigging up the phototube to open a door was a simple matter for engineers, but they soon found that with a little ingenuity it could be utilized to solve far more complicated traffic problems. It was installed in elevator floors to insure precise leveling off at landings. Light from a small bulb set in the edge of each floor fell upon the phototube, which actuated the braking mechanism at the correct moment. Another tube kept the elevator door from closing on last-second entrants.

Mounted before the vehicle door of a public garage, where pedestrians sometimes break the light beam accidentally, the tube will open the door for automobiles but not for people. For this job there are two beams several feet apart, and both must be intercepted or the tube will not respond. If a car emerges from the garage and breaks the beams in the reverse direction, the device doesn't open the door again behind it—it knows the difference.

The phototube has been adapted to all manner of jobs in the measuring and regulation of traffic. Installed beside a highway attached to a recording machine, it can be adjusted to count cars going in one direction, or both, and will also record their speeds. This is done by placing two invisible beams across the road some distance apart, with the tubes geared to ignore the brief interruption of a passing pedestrian. The speed of a car is calculated automatically, and sometimes such a trap is connected with an electric sign which flashes a warning to the speeding motorist. Such devices are also valuable in securing accurate data on traffic volume to determine the need for new highways.

One of the most striking examples of the electronic regulation of traffic is the elaborate system used on the Bay Bridge which carries commuters' trains between San Francisco and Oakland. By means of 4,000 electric relays, phototubes report approaching trains, give signals for the automatic setting of track switches and operate controls which establish car speeds. Phototubes also stand guard before vehicular tunnels, with the light beam as high as the tunnel's roof. If a truck comes along with too high a load, the beam is intercepted, a warning bell rings, and complications are avoided.

One of the phototube's most sensational roles is that of night watchman in warehouses, factories, stores and museums. For this purpose, beams of infra-red, or "black light" are used, since the phototube reacts to the invisible rays at either end of the spectrum. The black light from an inconspicuous source near the baseboard of a room may be reflected at a right angle by a mirror on the opposite wall to a phototube in another part of the room. The room can be crisscrossed with the invisible rays so that no intruder, even if he crawls on his belly, can enter without breaking one of the beams and setting off an alarm. A concealed camera with a flashbulb is sometimes added to snap the intruder for identification. Phototube circuits have also been installed to watch over sleepwalkers and mental patients, signaling a nurse if the patient leaves his bed.

At first these photoelectric devices would operate efficiently only over short distances and indoors, but now there are phototubes which react to a dim, distant light signal, and hundreds of factory yards, as well as approaches to piers, are protected by invisible, intangible barriers a thousand yards or more in length. Nothing short of complete blocking by a solid object will break the beam. You can even drape an overcoat over the phototube, and enough of the "black light" gets through to keep the circuit in operation. The phototube is indifferent to all light except that of the special beam to which it is attuned, for in front of the light which sends the beam there is a small revolving disk which chops up the outgoing beam into "slices" so thin that the human eye cannot detect them. The phototube, perhaps half a mile away, is adjusted to receive a signal of the same vibration as that served up by the revolving shutter.

There seems to be no definite limit—except that imposed by the curvature of the globe—to the possible length of these "invisible fences." Maxwell H. A. Lindsay, an engineer of the American District Telegraph Company, a pioneer in this field, set up a beam two miles long between two New York rooftops. The light source consisted of two ordinary 20-watt bulbs, with a filter which barred all rays except the invisible infra-red. He obtained perfect results, even on stormy days when the human eye could not span the distance. If this seems amazing, we have only to recall that Chicago's Century of Progress

Exposition was opened by the light of the star Arcturus, 220 million million miles away, which fell upon a photoelectric cell and caused it to turn on the lights.

Turning on lights is another of the sensitive phototube's chores. It can be adapted to respond to any desired intensity of daylight, and for this reason has been installed in schools, offices, streets and airports to turn on lamps when natural illumination falls below the needed level. Utility companies use it to warn them of the added load when storms blot out the sun and millions of householders turn on their lights. Mounted on the roof, it surveys the sky, and advises plant engineers well in advance of the rush.

In industry

Only a few years ago, electronic tubes were unknown in American industry, but now they are doing bread-winning jobs everywhere. In any plant where there is a conveyor moving along with a line of objects, the phototube is in its element. In the automobile factories, it counts painted fenders as they move along an overhead track. The light doesn't mar the finish, and it doesn't make mistakes. When packaged goods move down the line, it counts the sheep and tosses out the goats. The beam can be adjusted to weed out damaged or imperfectly sealed cartons. Put the light beam over a scale bar where packages are filled automatically, and it will stop the flow of material when the proper weight is reached, thereby dispensing with a human inspector.

No man or mechanical contrivance can count as fast as the phototube, and this proficiency has led to many industrial uses. For instance, when a width of finished cloth zips along between rollers, sometimes one side starts creeping up on the other, and if the "skew" is not corrected, ruined or inferior material results. If a phototube is mounted over each edge of the fabric, with a light bulb beneath, it will count the crosswise threads as they speed by, and if the totals begin to vary, it signals a mechanism which straightens the cloth. In printing plants, it insures accurate "register" of various colors on the page, and in many factories it scans thin sheets of material for pin-point holes.

In sheet-steel plants, the phototube measures the long, moving strip for cutting, and rhythmically orders the big shears to do their work. When an automatic process machine is clogged by material, the tube stops the machine and prevents breakages and loss of time. Installed in the maw of a giant stamping machine, the tube protects the operator. If his hand blocks the light beam, the jaws remain agape until it is safely withdrawn.

The fact that the tube will discriminate between the various wave lengths of color as well as between light and shade has made it invaluable to makers of paints, inks and dyes. The recording spectrophotometer, in which it is mounted, distinguishes more than two million different shades in the color spectrum, and has been adopted as a standard means of identification. In a simpler application, the tube will inspect oranges and throw out the green ones, or look at flour and determine its bran content. Brewers, makers of soft drinks and oil refiners put the beam through a pipe carrying the liquid. A change in color, indicating a change in content, is reported at once. It is reasonably predicted that in another ten years almost everything that we eat, drink, smoke, read, wear or ride in will be measured, weighed, sorted, counted or inspected by this tirelessly peering electronic tube.

Even more complex applications are being devised for the electronic robot. It watches the water level of reservoirs, rivers and lakes, making periodic reports by radio without human assistance. There is a hydroelectric substation in the Southwest over which electronic tubes have complete charge. They follow a specially made graph which shows the varying load of electric power normally used throughout the day, and methodically release the amount of water needed from hour to hour. And there is a machine which will take a drawing, scan it photoelectrically, and translate its lines into movements of cutting tools, ejecting the finished part. Several machines can be made to take orders simultaneously from the same master drawing, displacing a number of craftsmen. And the end is not yet.

These are a few of the jobs to which the light-sensitive phototube has been adapted. While it is the most versatile tube of the lot, it is only one of some 750 tubes in the prolific electronic family, and it would be of little use—except in scientific laboratories—without the assistance of some of its more complex relatives, which free electrons by means of heat.

In 1883 Edison became an unwitting pioneer in electronics because the life of his early carbon-filament light bulb was shortened by blackening. He found that particles of the carbon were being carried over in some way to foul the inside of the bulb, and that these specks appeared to be negatively charged, so he sealed an extra piece of wire into the bulb and hooked the outside end to the positive terminal of the battery, hoping that it would collect the flying particles. This dust trap did not work, but he found that the hot filament did give off electrical energy which crossed the gap and set up a current in the extra wire.

"As I was overworked at the time in connection with the introduction of my electric light system I did not have time to continue the experiment," he said later. The following year, however, he patented a similar bulb.

His observation aroused great curiosity among other experimenters, and in 1904 John Ambrose Fleming of England built this principle into a thermionic (heat-actuated) electronic tube. With a metal plate in the bulb to capture the fugitive electrons, this roughly paralleled the light-stimulated phototube. The value of Fleming's tube became apparent at once. Since the tube was a one-way street, it would take alternating current and change it into direct current—a knack which is now saving millions of dollars and untold man-hours in our war-production plants. And it would take radio waves, whose frequency is too high to produce audible sound, and change them into the original low-frequency sounds that were fed into the transmitter, thus enabling them to vibrate the diaphragms of receiver headphones. But it would not amplify the broadcast waves, for it could not regiment the leaping electrons.

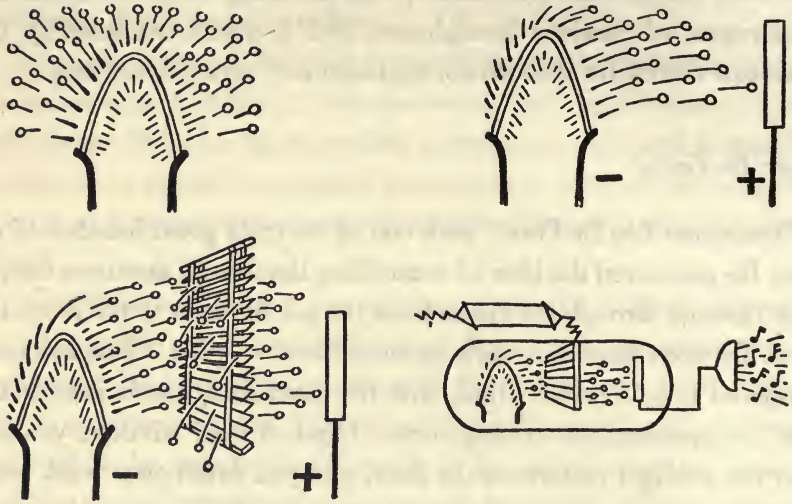
Enter De Forest

Then came Lee De Forest with one of the truly great hunches of all time. He conceived the idea of controlling the flow of electrons during their passage through the space from the hot filament to the receiving plate. Between these two parts he introduced a "grid." This has been compared to a Venetian blind, with the controlling cords outside the tube. By opening and closing such a blind at your window, you can alter the sunlight pattern on the floor, and you could even work out a clumsy communication code in this manner. De Forest's electronic blind worked a million times as fast, and was far more delicate in its control of the stream of electrons.

Without this invention, radio, as we know it, could not exist, for this is the amplifying tube which is an essential part of every modern receiving set. The lead from the aerial is connected to the grid, and by operating this "Venetian blind" to increase or diminish the flow of electrons, the tiny amount of energy which actually comes through the air from the radio station impresses its pattern upon the much greater current which flows through the tube from your baseboard light socket. Vastly more powerful than the original stimulus, but reshaped by the grid in its sound-carrying mold, the current can now operate your loud-speaker. By hooking up several tubes in a series, any amount of amplification can be obtained. In a small portable radio, four tubes the size of your little finger multiply the power of an incoming radio signal twenty-five billion times between the aerial and the loud-speaker.

Geared to a phototube, the amplifier behaves in much the same way. When the beam is broken, the phototube sends a feeble impulse to the

HOW THE RADIO TUBES WORK



These sketches help to explain the workings of the amplifying tube—one of the simplest of the great family of electronic tubes—which is indispensable to your radio and to many other electronic devices. To begin with (A) when the tungsten filament in the tube is heated by electricity, electrons boil out of it. Then (B) the freed electrons, which are negatively charged, are attracted by the positive electrode in the tube, and leap across the gap, setting up a current. (C) The third element in the tube, the grid, may be roughly compared to a Venetian blind which can be opened and closed thousands of times a second. When it is open, electrons can pass through freely; when it is closed, most of them are barred. We can now see (D) what the amplifying tube does in the radio receiving set. The tiny amount of radio energy caught by the aerial operates the "blind," thus impressing its pattern upon the much greater current which flows through the tube from the baseboard light socket. Vastly more powerful than the original stimulus, the electronically amplified current can now operate the loud speaker. By hooking up several of these tubes in a series, any amount of amplification can be obtained. (Sketches by courtesy of the General Electric Company.)

grid. The blinds are yanked open, electrons pour through, and the power operates a magnet which pulls a switch shut, which starts a small motor which opens a door, or does whatever task it is given.

Parade of giants

The addition of De Forest's grid raised the curtain on a panorama of staggering electronic possibilities, and the advances of recent years are only an indication of what the future is bound to bring. A galaxy of brilliant scientists and engineers including Einstein, Millikan, Armstrong, Langmuir, Hull, Zworykin, Alexanderson and the Varian brothers have charted the electron's behavior, and have built up the little glass tube into a series of Goldbergian metal giants which have everything but a conscience. More hurdles were placed in the tube to guide the acrobatic electrons in varied jobs both delicate and powerful.

Due chiefly to the classicists of the General Electric Company, which has played a large part in the development, the new tubes have names as imposing as their functions. Man's destiny is now shaped by ignitrons, thyratrons, kenotrons, pliotrons, phanatrons, iconoscopes and klystrons, to mention a few.

There is a group of high-frequency radio waves which induce heat, when they are concentrated instead of being broadcast, and this fact has opened a whole new field in therapeutic and industrial electronics. Several years ago, Dr. Willis R. Whitney, then director of the General Electric Company's research laboratories, exposed a cockroach to these short waves and roasted it to a turn. Later it was found that men who worked with such waves were running temperatures. This led to the "fever machine," used to induce heat inside the human body in the treatment of disease. For years, scientific demonstrators have been using the tube to pop corn and roast hot dogs with amazing speed. Unlike ordinary heat waves, which bore from without, the radio waves penetrate the whole object instantly, and the heating time is cut to a fraction. Now this tube, the pliotron, is used to surface-harden metals in a tenth of the time once needed. Airplane parts of laminated plastic-plywood (composed of alternate layers of wood and synthetic resin) once had to be baked in an oven for hours. With its penetrating, heat-producing waves, the pliotron does the job in minutes and the finished part is stronger. Using the same principle, RCA's threadless, needleless electronic sewing machine stitches synthetic raincoats together by fusing the seams with radio waves.

The kenotron does other new tricks. It will detect weak spots in the insulation of cables buried underground. In the Precipitron, the new Westinghouse air filter, it charges dust negatively so that it is attracted to positively charged plates, thus cleansing the incoming air of particles too small to be removed by other air-cleaning devices. This is of great value in plants where the manufacture of optical and high-precision instruments have set new standards of air cleanliness, and it has even made possible the use of white curtains in a Pittsburgh home. By a similar method, the kenotron operates a new electronic spray gun for painting automobile bodies. The negatively charged paint flies without waste to the positively charged surface of the body. In the manufacture of sandpaper, it shoots the abrasive particles to the adhesive paper with the sharp ends up.

The liberated electron has come to the rescue of our hard-pressed war industries in ways too numerous to catalogue. For instance, we could not have achieved our present air supremacy over the Axis if our aluminum plants had not increased production seven-fold. Great quantities of direct current are used in the electrolytic process by which aluminum is made. Power is usually delivered in A.C. form, and has to be converted to D.C. to do this work. There are mechanical converters for the purpose, but they use steel and copper badly needed elsewhere. So an electronic tube called the ignitron took their place, converting the current much more efficiently, with a great saving in materials. The ignitron is not only a superb pinch-hitter—it has come to stay.

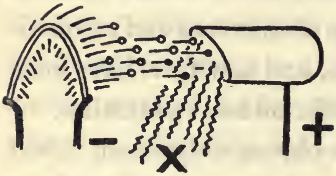
In the laboratory

While mountains are being moved by the use of the new electronic tools, they may make their greatest contribution to man's well-being in the laboratory. Peering through the new electron microscope, which is 100 times more powerful than the strongest light microscope ever built, scientists have seen for the first time in history photographic "stills" of the actual battle between disease bacteria and the friendly bacteriophage. Some indication of the significance of the new instrument in fighting disease was shown early in 1944, when Dr. Gregory Schwartzman of Mt. Sinai Hospital, using it to examine the blood of a heart-disease victim, observed virus-like organisms never before encountered in the human blood stream. The viruses of influenza and meningitis have been photographed for the first time, and new facts have been learned about the structure of metals, synthetic rubber and textiles.

The best optical instrument can magnify objects only about 2,000 diameters, and is limited by its inability to reveal particles whose diameter is shorter than wave lengths of light. When infinitesimal electrons are used instead of light waves, this limitation is overcome. In a big, upright, metal cylinder, with peepholes around the bottom for several observers, a heated tube emits electrons which bombard the object to be examined, and instead of the glass lenses which control light rays, there are electromagnetic coils to control the electronic stream. The electrons penetrate the object and record its likeness on the fluorescent viewing screen or the photographic plate. This microscope was invented in Germany in 1931. Introduced in this country by the Radio Corporation of America less than four years ago, it is already in use in some fifty university and industrial laboratories. Dr. Vladimir Zworykin of RCA, who played a leading part in its development, foresees improvements which may increase its power to 1,000 times that of the light microscope. This would bring atoms and molecules—the universal building blocks whose structure scientists can only hopefully approximate with symbolic diagrams—within the actual range of human vision. If the new science of electronics had brought forth nothing but this instrument, its effect upon man's future would still be incalculable.

Revolution in X-rays

New developments in the X-ray tube, another electronic device, have come so fast in recent years that experimenters have not yet had time to discover all their potentialities in industry and in the diagnosis and treatment of disease. These penetrating electromagnetic waves, named "X" because they baffled their discoverers, are produced in the tube by freeing electrons from heated metal and causing them to bombard a positively charged metal target. The collision releases the X-rays from the atoms of the target. The higher the voltage used to drive the electrons across the gap, the greater is their speed and the shorter and more penetrating the X-rays. The longer waves that are easily absorbed are called "soft X-rays," while the shorter rays are called "hard."



High-speed electrons, striking metal atoms, make those atoms give off penetrating X-rays. (Courtesy General Electric Co.)

Only a few years ago, X-rays produced by 100,000-volt tubes, which are about a millionth of a millionth of a centimeter in length, were the hardest rays in common use. Today more than fifty war plants are equipped with million-volt X-rays, so hard that they will penetrate eight inches of steel and reveal hidden defects. Late in 1944, these units were dwarfed by the appearance of an industrial X-ray unit of 2,000,000 volts, so powerful that it would reveal a tiny bubble or defect through twelve inches of steel armor plate. And Professor Donald W. Kerst of the University of Illinois has developed a method for producing vastly more powerful rays, which may revolutionize X-ray therapy and rival the electron microscope in pushing back the boundaries of knowledge. This is done by whirling the electrons round and round through a glass "doughnut" for a total distance of many miles, working them up to astronomical speeds before they crash into the target. Using this principle, General Electric scientists have produced, for the first time, X-rays with a potential of 100,000,000 volts.

Electrons accelerated to such dizzy speeds may surpass X-rays themselves in the treatment of disease. The target may be abandoned and the stream of electrons poured directly into the patient's body. While X-rays pass entirely through the body, it is predicted that the electron beam can be controlled to reach any desired part of the body, and no further.

X-ray machines have also been improved in mobility and speed of operation. A mass-production unit made by Westinghouse, mounted over a moving conveyor in a Midwestern war plant, X-rays metal airplane castings for defects at the rate of one every five seconds. A new field hospital X-ray unit, recently ordered in large numbers by the Army, locates a bullet or shell fragment, both for position and depth, in one minute, and also marks the spot with iodine to guide the surgeon.

—*and television*

Television stands high in any list of new projects calculated to take up the anticipated postwar slack, and makers of equipment are waiting only for the war's end to bring movies-from-air-waves into everyone's home. Before the war interrupted development and distribution, between 6,000 and 7,000 home receivers had been sold in the United States, and today only eight stations broadcast televised programs. As this is written it is not yet clear whether postwar manufacturers will be allowed to sell television equipment based on present technical standards, or whether they will be required to postpone their sales campaign until the great wartime advances in electronics can be utilized to provide vastly improved television. Whichever side wins out in this controversy, some idea of the potential importance of the new industry may be gained from the fact that the "bird in the hand" faction believe they can sell three-quarters of a million sets in the first eighteen months after materials are released, and that some eighty applications to construct new television stations after the war have been filed with the Federal Communications Commission.

In television, the freed electron performs acrobatics so complicated that it makes a phototube look like a relic from the Stone Age. The phototube, like a single tiny rod of the human retina, detects the variations of only one spot of light, but the iconoscope—the seeing eye of television—sees life whole by means of thousands of small, light-sensitive cells which approximate the entire system of rods and cones of the human retina.

Yet with all its complexity in practice, the basic principle of television is simple. Anyone can transmit a picture to a friend by electrical energy without leaving his desk. You simply rule off the picture into small squares, phone your friend, and ask him to prepare a ruled paper of the same size. Then you begin at the upper left corner of your picture, while he follows you with his pencil, and announce: "Black, white, gray, black," etc., reporting the light intensity of the squares, line by line, until you reach the bottom. By filling in the squares, he can create an approximation of your picture. If you want movies, you have only to take the next picture in a motion sequence and repeat the operation, and so on. By binding the sheets together and flipping them, your friend can make the figures appear to move. If you both have patience, fortitude, strength and determination, and live to be a thousand years old, you can approximate the effect of television.

For that is exactly what television does. It reads off squares of light and dark, row after row, in the picture, and translates them to a radio message which it sends over the air. The intensities of light, like those of sound, can be turned into radio impulses and later reconverted into the original medium. The receiving set, like your friend, "hears" the impulses, bit by bit, like the telephoned directions, and paints each little square in sequence with the same light intensity as the original picture. But the darting electrons do all this with infinitely greater precision and fidelity, and so fast that at least six complete "frames" are completed before a human being could even touch pencil to paper.

This basic principle of television was suggested sixty years ago, but no equipment existed to implement the plan. In the late twenties, television experiments were made in which rotating disks set with mirrors, or perforated with a spiral row of holes, picked up light impulses which were "read" by phototubes and translated into radio impulses. But as in a hundred other fields, the electronic tube, which has no moving parts, makes no noise, and is faster and more accurate, quickly supplanted the mechanical devices.

The iconoscope, the invention of Dr. Zworykin, which is now used in most television cameras, is a big tube which contains what may be called a screen and a pointer. The scene to be televised is focused by the camera lens upon the screen, which is composed of many thousands of light-sensitive particles. Each particle stores up voltage proportional to the intensity of the light falling upon it from the corresponding bit in the scene. The pointer is a stream of liberated electrons, which is guided back and forth across the screen by magnetic coils thousands of times a second. The pointer releases each tiny charge in succession, and the picture takes to the air at the rate of thirty "snapshots" a second. In the receiving set, a similar pointer composed of magnetically directed electrons transmits the picture-messages to a sensitive screen faster than the eye can follow.

Present television has hampering limitations. Its depth of field is not adequate for showing a group of actors on a stage with the clarity of detail which a movie-going public has learned to expect, and there is a tendency for a television entertainment to resolve itself into a procession of individual performers. A recent invention called the orthicon, an improved television camera eye developed by RCA, may do much to correct this failing. Its sponsors claim that it can "see" any image visible to the human eye, and that it will even make possible the televising of sports events on cloudy days.

As the television controversy now stands, several leading makers of equipment wish to go into production immediately after the war with home receiving sets based on today's standards, which they plan to sell for about $200. The other faction, headed by Columbia Broadcasting System, claims that such sets would soon be obsolete and that their wide sale would slow up the full commercial development of the new medium. They believe that by waiting to take advantage of wartime research which will make possible the use of shorter waves in the television spectrum than have been employed before, we can have television twice as good as the best of today. To test its contention, CBS has placed an order for an experimental station to be installed in the tower of the Chrysler Building as soon as materials can be obtained.

The crystal ball

Since one or more electronic tubes can be made to do almost any task the human mind is capable of imagining, no one can go far wrong in brave-new-world prophecies, and without romancing one may foresee expansion in numerous directions. Recent growth has been impressive. In 1943, more than 25,000,000,000 kilowatt-hours, or about ten per cent of all the electrical energy generated in the United States by any source of power, passed through electronic devices. The dollar volume of sales of electronic goods in 1941 was about $300,000,000 and the best estimates for 1944 run in the neighborhood of $4,500,000,000—an increase of 1,500 per cent. Much of this increase is due to the demand for war communication devices, many of which may not be needed in peace time, but the added plant capacity doubtless stimulates a fervent desire among manufacturers to increase the list of electronic devices.

Spurred by wartime inventions which are now secret, radio, television, and all other forms of electrical communication should telescope the normal advances of a decade into less than five years. Travel by plane, ship, railway or automobile should be safer. Eyes will pierce fog at sea; planes will land surely in storm or darkness, and will see mountains a hundred miles ahead. Trains will not collide. Radio traffic signals at intersections on high-speed highways may advise drivers in time to save tires, brakes and lives, and it is possible to mount phototubes on cowls to enforce automatic, reciprocal dimming of headlights.

Telegrams are already sent by facsimile in the handwriting of the sender, and tomorrow we may have automatic slot machines in corner drug stores which will receive and transmit written messages in facsimile. This method will be of great value as a bridge between languages. Today, if a Chinese in the United States wishes to cable his home, the message is dispatched in a numeral code in which the 9,000 most commonly used Chinese characters are represented. Western Union's Telefax units, which transmit any black-and-white design in facsimile, are now being installed in China's telegraph system to speed up military communications. Eventually, telegrams will be sent anywhere in any alphabet without the costly nuisance of coding or translating. Newspaper pages, blueprints, fingerprints and formulas can be sent by the same method, which is many times faster than telephoto.

Television in color has been thoroughly tested, and three-dimensional television, already achieved experimentally, will come when the demand justifies it. Engineers know how to make electronic kitchen ranges which will cook a roast in a few minutes, regardless of size, without heating the roasting pan. No less an authority than Dr. Irving Langmuir states that it should be possible to build an electronic machine to scan fruit trees, locate the ripe fruit, and direct mechanical arms to pick it from the branches.

Dr. Orestes H. Caldwell, electronics expert, foresees FM radio stations which will broadcast both programs and electric power. Or if this is slow in coming, electronic tubes may easily make practical the transmission of power over wires for a thousand miles. Carried to its conclusion, this would mean, for instance, that Pennsylvania coal, converted into electric power at the mineheads, could light every bulb and turn every factory wheel in the Eastern United States, with the virtual elimination of coal haulage and city smokestacks and consequent improvement in public health and reduction of cleaners' bills.

These are only samples of the glittering array of revolutionary machines and gadgets which have been proposed. The ones which are most useful or which appeal most to buyers, and which can be sold at a price people can pay, will soon make their bows.

Whatever the future of electronics may be, it is great and it is unpredictable.

CHAPTER TWO

SPIES WITH GLASS EYES

WHEN ALLIED INTELLIGENCE MEN interviewed German and Italian prisoners after the whirlwind finale of the Tunisian campaign in the spring of 1943, they were puzzled by the belief of captured artillerymen that the Americans had used some sort of secret weapon to knock out their gun emplacements. Firing at night, the Americans had spotted their guns with pin-point accuracy, missing none of them by more than a few yards. They could not understand how their positions had been discovered, since the guns had been moved only a few days before.

The same "secret weapon" baffled the Japanese at Guadalcanal, at Kula Gulf, at Truk, and many other spots in the Pacific. It enabled British and American planes to blot out German robot-plane installations on the French coast, and by its aid Allied bombardiers have been plucking essential Nazi factories from surrounding structures as cleanly as a dentist takes a tooth from a gum.

The weapon, hardly secret but one of the most important in the Allied arsenal, is the modern spy, the camera lens. The Mata Haris doubtless did very well in their day, but in World War II they are victims of technological unemployment. General staffs no longer wait —if they ever did—for scented hetairas of Oppenheim ilk to wheedle plans of fortifications and offensives from bemused enemy dupes. They send over a Lightning or a Spitfire fitted out with the newest photographic equipment, and secure reliable documentary evidence in less time than Mata needed to dress for an embassy reception. While the methods of old-fashioned espionage have not been completely abandoned, it is estimated that eighty per cent of the intelligence information behind any given military operation is now obtained by the flying camera.

What happened in Tunisia has since been reported by Col. James G. Hall of the Army Air Forces. To begin with, the attack was postponed because of bad weather—weather that would not have hampered ground forces, but which grounded reconnaissance planes, the eyes of the Army. When the weather cleared, the fast, high-flying planes went over and took hundreds of photographs of the enemy positions. Prints were quickly made and pasted up into a great mosaic reproduction of the entire enemy area. Trained interpreters, using a battery of new appliances, high-lighted guns, troop concentrations, natural elevations and other pertinent features and turned over their data to artillery commanders. Instead of training their guns by maps in the traditional way, they chose this time to use the interpreted photographs. As a result, the Axis guns were knocked out, resistance was completely crushed, and Tunis fell in twenty-four hours with few casualties.

The secrets of Truk

Truk, the great Japanese naval base in the Carolines, was pretty much of a mystery before two Liberators carrying Marine Corps camera men pried the lid off its secrets. Few white men had been allowed at the base since the Japanese occupied the islands in 1914. Even if our Navy had obtained complete plans of the base, there was no way of knowing on the morning of February 4, 1944, how many warships the harbor held, how many planes were on duty at the airfields, or what recent installations had been made. The Marines' bombers, carrying no block-busters but bristling with glass eyes, flew 2,000 miles that day to make a careful photographic inventory of the crowded shipping, the air fields, and the palatial living quarters. Every line and dot on the prints told their story as officers examined them at American headquarters, and Admiral Spruance learned exactly what opposition to expect, what size task force would be needed, and what great rewards could be gained from a successful assault. Three weeks later our warships descended on the base in one of the most devastating raids in the history of naval warfare.

These are only outstanding examples of photographic spy work. Every engagement is preceded by fast planes armed only with cameras, and manned by cool-headed specialists whose business is to get their pictures and run for home. In preparation for the bombing of the Ploesti oil refineries in Rumania, a great mosaic map was made from thousands of aerial photographs. Using this map and other intelligence data, engineers built a full-scale dummy of the refineries in the Libyan desert, and the aerial task force practiced over this target until they were letter-perfect in every detail of altitude, timing and division of labor. As a preface to the Anzio beachhead landing, snapshots of the shore line and a ten-mile strip behind it were pasted up, and 20,000 rotogravure prints were quickly made, so that every platoon commander had an accurate picture-map of the terrain.

Aerial photography has rapidly become big business. Army authorities have stated that since the war began, 8,000,000 square miles of the earth's surface has been photographed by American airmen—an area twice the size of the United States. One photographing and processing plant in Italy has a turnover consistent with a $100,000,000 annual business in civilian life, and in one month alone its output was 1,250,000 prints. These figures are impressive, but even more arresting is the story of the new cameras, processing apparatus, films and techniques which bare enemy secrets to the high-flying eyes of modern espionage.

Like many military operations, camera spy work is roughly divided into tactical and strategic missions. In the former, reconnaissance planes photograph single objectives in response to immediate need for information by field commanders, while in the latter category, systematic flights are made over large areas to secure data for aerial mapping as an aid to planning an entire campaign. Naturally, there is considerable overlapping of these functions, and pictures snapped for either purpose may fill both needs.

As an example of quick action in an emergency, a field commander may radio an observation plane, already aloft, to fly to point "X" and snap a highway junction which is a bottleneck for enemy reinforcements. Reaching the spot may take only a few minutes in a reconnaissance plane stripped for speed. The observer may snap his picture with a long-focal-length camera from 30,000 feet or higher. While the plane is dashing for home, he quickly develops the film in a non-spill processing tank which is electrically heated to the desired temperature, and makes his print by touch, with one hand inside a light-proof bag, on waterproof paper which sheds moisture and needs no drying. The print is slipped into a metal cylinder equipped with shock absorbers and dropped to the ground at a prearranged spot where a man in a jeep rushes it to headquarters. Under certain conditions it is often possible to drop the finished print to the courier within five minutes after the click of the shutter. With a magnifying glass the photographic interpreter can count trucks and identify guns and mobile equipment from pictures taken five miles aloft, and artillery can shell the junction while the enemy force is still concentrated.

Flying dark-rooms

Some of the bombers used on photographic missions carry fully equipped tent dark-rooms which can either be set up and used in the plane, or packed in a box the size of a small blanket chest for delivery to ground forces. It can be set up in the field in fifteen minutes. Telescoped metal tubes serve as poles for a small gambrel-roofed, lightproof tent with a zippered door. A small air-conditioning unit provides the right temperature for any climate. The container box becomes a water-tank, and water for processing films is dropped in tough, pliable plastic bags.

One picture may be enough to reveal a temporary enemy concentration, but changes in shipyards, factories and fortifications are often followed by a series of photographs made over a long period. If the enemy is building an airplane plant, it is better to let him finish the job before bombing it, thus cancelling more material and labor with the same weight of explosives. Repeated pictures of the same region reveal to interpreters new geometric designs which they have learned to associate with certain types of factory, and wheel-tracks on a peaceful meadow, caught by the camera in the early morning, may betray camouflaged gun locations.

Observation planes on strategic missions may spend months contributing, bit by bit, to a composite picture of a large area. Early in April, 1944, it was reported that more than 200,000,000 photographs of Western Europe, covering every inch of the "invasion coast" from Denmark to the Spanish border, had been made by British and American reconnaissance planes. Few details of the German defense system escaped these flying cameras. In addition to high-altitude photographs, profile shots of many parts of the terrain had been taken by ground-skimming planes to provide landing-barge views of coastal areas.

Our flying photographers had good pre-war experience in aerial mapping in such projects as the air surveys of the Dust Bowl and the TVA and Boulder Dam projects. Lumber companies commission air maps of forest areas to estimate their timber yield; oil firms use them in their constant search for ground formations which suggest petroleum deposits, and the Department of Agriculture has employed the method to estimate planted acreages of various crops. In Canada, aerial mappers have discovered 10,000 lakes unknown to surface-bound explorers, and the American Geographic Society's recently completed giant map of South America—the most detailed continental map in existence—could not have been drawn without the use of thousands of aerial photographs.

Pioneer Fairchild

A host of fliers and engineers have contributed to the new art of aerial mapping. One of the ablest and most confident of the pioneers in the field was Sherman Mills Fairchild, who twenty years ago formed an aerial survey firm, using a mapping camera of his own design. Fairchild was an unusual combination—an inventor who could afford to lose money. From childhood a confirmed gadgeteer, he began to study aerial photography when he was taken from college and sent to Arizona for his health during the first World War. Flying photographers of that vintage were leaning from the cockpits with hand cameras, and efforts to make successive photographs through a hole in the cabin floor were rather crude. Fairchild went to the War Department in 1918 with plans for an efficient automatic aerial camera in which exposures would be synchronized with the speed of the plane. He received orders for a number of cameras, which he built at a loss, too late for use in the war. The camera was a success, but the first aerial mosaic maps were far from accurate. Objects at the edges of the pictures were distorted, like the man at the end in a banquet photograph, and if the plane were not held on an even keel, the tilt created other distortions. Fairchild wrestled with these problems. Since then his survey firm has mapped enormous areas in the United States and elsewhere, and his military aerial cameras have been adopted by the United States and many other countries.

The aerial mapper flies back and forth over the section to be photographed, much as a farmer mows a field, and the more territory he can get in one shot, the wider his strip and the sooner he will finish the job. This is of particular importance in wartime, with ground gunners and interceptor planes on the alert to destroy pictures that may be of more value than an army division. Wide-eyed lenses have been developed to speed the job. Bausch and Lomb's Metrogon lens, now being used by the Air Forces, has a range of over ninety degrees, and with one snap of the shutter three miles up it can take an area of twenty-eight square miles so sharply that motorcycle troops can be counted throughout the entire area. One Army camera recently photographed an area of 1,600 square miles in about an hour from 30,000 feet. In many observation planes, three Metrogon-lensed cameras are mounted, one pointed straight down, the other two fixed at forty-five degree angles at the sides. Even at a low elevation they blanket the country from horizon to horizon, with large overlapping areas.

Aerial mapping means a great deal more than taking contiguous pictures of the terrain and piecing the prints together. Aerial maps are made which give military leaders not only a detailed flat picture of the countryside, but a three-dimensional effect, with means of determining within a few feet the depth of valleys and the height of hills and buildings. This technique has revolutionized the making of contour maps. In less than five days' flying time airmen snapped the entire state of Massachusetts, securing data for a map which it would have taken ground surveyors years to collect.

To secure the three-dimensional effects which the strategists use in planning military movements, the aerial mapper actually takes two pictures, from different vantage points, of all the terrain he covers. When he begins his work he considers the speed of his plane and adjusts a small control on his instrument panel which sets the time interval at which the big automatic camera will snap. His pictures must overlap sixty per cent longitudinally and perhaps thirty-five per cent laterally, to provide two shots of everything, with a safe margin. If he flies over a bridge, for instance, the camera may make one shot of the north side, and another slightly to the south. The distance between the shots may be a mile or so, depending on the height of the plane.

Giant's eye view

If you can imagine a giant so huge that his eyeballs are a mile apart, you can get an idea of what the camera is doing. We see nearby objects "in the round," not as flat planes, because the angle at which our two eyes focus tells us how far away the different objects are. But when we observe things at a distance, they tend to merge into a single plane. This is because the base of the isosceles triangle (the distance between the eyeballs) is so short compared to the two long legs of the triangle that the difference in angle is too small to serve as a guide. By greatly increasing the length of the triangle's base, the mapping camera provides "giant eyes," enabling the strategist to gauge contours and elevations from twin pictures taken five miles aloft as clearly as we can in looking at a child's sand castle at our feet.

Research men have spent years perfecting the equipment which bridges the gap between the mapping camera and the amazingly vivid contour projections which Army interpreters and engineers finally see on the screen or viewing table. When the films from the mapping camera are developed, some of them are true vertical shots, some are askew because of a momentary tilt of the plane, and others are oblique shots of terrain two miles or so to either side of the plane. By means of complicated rectifying printers, all the pictures are transformed into matching vertical views which appear to have been taken directly above the scene.

A number of devices, simple and complex, are used to obtain visual perspective in viewing the twin pictures. The most elaborate and effective of these is the Multiplex Projector. When positive transparencies are made from these photographs and placed in the overhead projectors, a three-dimensional picture showing many square miles of territory is spread out on a smooth metal-topped viewing table. By wearing special glasses, you can gaze down a dizzy precipice, or almost prick your finger on a church spire. Trees spread their foliage in sharp relief against the sod beneath, and the comparative heights of hills and buildings are obvious at a glance.

One method used to get this effect is the same employed from time to time in special motion-picture shows when eyeglasses with one red and one green lens are distributed, and wild beasts and locomotives appear to charge from the screen. The projectors which throw the scene on the viewing table—there may be from two to a dozen of them—are alternately covered with red and green filters, so that there are actually two complete images of the area, one to be seen by each eye. Without the special glasses, the scene is a hazy jumble of red and green lines, like an "off-register" color-printing job, only worse. With the glasses, one eye sees red, the other green, and the jumbled lines fuse into a single, clear, three-dimensional image. In effect, the observer's eyes are now a mile apart, and he has a "giant-view" perspective.

Military interpreters need not rely entirely on visual judgment in computing ground elevations. Suppose an invasion or raid is planned, and the Corps of Engineers has to select the best spot for throwing a pontoon bridge across a river. They are looking for a place where the banks slope gently and the surrounding terrain presents no serious obstacles to motorized equipment. They take a small viewing stand a few inches in diameter, which outwardly resembles a table microscope, and move it about on the projected river system. The device throws a pin-point of light on the picture. The observer raises or lowers the stand with a finely-calibrated turnscrew until the dot of light appears to rest on the surface of the water. He takes a reading, turns the screw until the dot has been elevated to a hilltop, brings it to rest, and takes another reading. The difference on the scale tells him the height of the hill. So accurate is this method that from pictures taken at 20,000 feet the height of a mountain can be calculated with a margin of error of only a few feet.

Contour maps of the site for the planned river crossing, showing elevations suitable for gun emplacements, may be quickly turned out from the projected photographs. Attached to the movable stand there is a fixed pencil. The map maker slips beneath the stand a sheet of drawing paper, which then becomes the screen upon which the projected picture appears. By moving the stand about so as to keep the dot of light resting on the surface of the illusory ground, he draws an irregular line, such as may be seen in printed maps, which passes through all points where the ground is of the same elevation. A series of such lines creates an accurate contour map, which may be rapidly duplicated and sent to field commanders.

In determining absolute altitudes for these maps, known values, like that of sea level, are used for control purposes. In the peacetime mapping of inland tracts where there are few known altitude reference points, aerial photographers sometimes do their work first, and ground surveyors later establish a few altitude points for the guidance of the map makers.

A similar three-dimensional effect is obtained without the use of colored filters, by the use of light-polarizing films and spectacles, which is one application of a fascinating new optical development to be described in the following chapter.

These table projectors are portable but bulky, and there are a number of small stereoscopic devices, some of them pocket-size, which enable men in the field to look at paired aerial photographs three-dimensionally, just as our grandparents did with their parlor stereoscopes. And by diligent practice, many photographic interpreters have learned to see twin photographs in relief without optical aids. They do this by spreading the axes of the eyes so that each eye sees only one photograph, and is focused upon a building or other point which appears in both pictures. After a little the images fuse, and the natural contours of the ground become apparent.

Many other types of camera have been developed to perform the varied tasks presented by the war. One of the newest, developed by Col. George W. Goddard, chief of aerial photographic research for the Air Forces, is a shutterless camera which will take one continuous picture of a strip of ground as long as 200 miles. Its operating principle is similar to that of the revolving camera which is used to take class pictures. The film rolls past the open aperture at a speed synchronized with that of the plane. Used on fast, low-flying planes, this camera is ideal, for instance, in securing an accurate tally of the units in a motorized column, and eliminates any confusion which may be caused by the periodic, overlapping shots of other cameras.

And there is an automatic camera which will point in any one of four directions—obliquely forward, backward, or to either side—in obedience to a control device on the pilot's instrument panel. The pilot of a low-flying bomber photographs the target ahead of his plane, and presses a button. There is a grind of meshing gearwheels as the camera turns its eye to the rear, and begins taking pictures, at the rate of three a second, of the bombed target.

The telephoto lens, a cylindrical tube built like a telescope which has a focal length of as much as sixty inches, makes it possible to take large-scale pictures from a plane five miles up. Its first test pictures were distorted because the contraction of the metal casing in the extreme cold of the upper air forced elements of the compound lenses out of position. Then the General Electric Company produced a fitted blanket wired for heat, like the suits worn by fliers, and the problem was solved. Similar electric blankets now enclose many of the cameras designed for high-altitude work.

Infra-red magic

For years, haze held the flying cameramen to low levels. This layer is now penetrated from high altitudes by means of infra-red photography, in which pictures are taken by rays of "invisible light" outside the range of the human eye. Any amateur who wishes to try this technique can take pictures in total darkness with an ordinary camera, using a special film sensitive to infra-red, or heat waves, and a couple of electric flatirons in place of photofloods to "light" the subject.

Phenomenally clear pictures at great distances are possible with infra-red equipment. Major Stevens of the Army Air Corps took good pictures of Mt. Shasta from a distance of 300 miles, and a detailed photograph of the New York skyline was made recently from a plane hovering over Philadelphia. Physicists explain that the long infra-red waves sweep through the haze particles unimpeded, just as the long swell of the ocean sweeps through a line of piles. Short waves in either case splash against the obstacles and are diffused. Fliers make the sensational long shots by covering the lens with a dark-red filter which bars out the confusion of the splashing short waves and passes only the long ones which have kept their form. The special camera film treated with dyes sensitive to the long rays completes the process.

The infra-red technique has not only pushed the photographer's ceiling beyond the range of effective ground fire—it has turned the whole art of camouflage upside down. Leaves and grass come out a snowy white in the picture, since their surface green is transparent to infra-red rays, and the lighter tissues of the plants are captured by the lens. Green paints and other artificial coloring matter used to disguise batteries and plane hangars are not transparent to the rays, and often betray the position of enemy structures by their conspicuous darkness in the picture. This has made the work of the camofleur more difficult and complicated.

Color pictures while you wait

Color photography is one of the newest and most promising techniques in the art of aerial spying. Good color photographs have been taken from the air for some years, but since the films had to be sent to the manufacturer to be developed, the process was of little use in a military way. Now color films can be developed in a portable dark-room at the front, or anywhere else—an improvement which will be of great interest to postwar amateurs.

Col. Goddard was the Army's pioneer in this field, as he has been in many other innovations. In transforming color photography from an amateur's delight to a practical reconnaissance weapon, he took hundreds of aerial shots of cities, factories and rugged mountain terrain, trying out new equipment and methods and pushing the effective altitude higher and higher.

To check the accuracy of color reproduction, long strips of felt, dyed in tested colors, were spread on the flying field and photographed from various altitudes. When he made pictures from the dizzy heights where fliers wear oxygen masks, Col. Goddard found his films overlaid with dull blue from the perpetual layer of haze which occurs at 13,000 feet or so. Since the infra-red technique could not be used with color film, special filters were devised to penetrate this haze. Today, Army and Navy planes, using standard aerial cameras, are making amazingly clear, detailed color shots from high altitudes.

Pictures in natural color are of great value in identifying enemy installations and penetrating the veil of camouflage. In black-and-white photographs, grays, greens and browns often look alike. In a color picture, a yellowish patch of freshly dug earth leaps to the eye. Foliage wilted by gunfire reveals a battery emplacement, even though the gun itself has been carefully camouflaged. Synthetic rubber factories are identified by a yellowish tinge in the smoke. And by its vivid contrasts, color gives a three-dimensional effect which is absent in ordinary black and white.

Goddard's flash bomb

One of the most valuable gadgets of World War II is a fast, brilliant flash bomb—the invention of Col. Goddard—which enables planes to take clear pictures in the dark without being seen themselves. Night photography has become increasingly important. In the early days of the war, daylight casualties among British aerial observers sometimes ran as high as sixty per cent a week. And night pictures are often more revealing, since troops and guns are moved to new positions under the cover of darkness.

Foreseeing a wartime need, Col. Goddard began experimenting in the middle twenties with the aerial flash bombs. Once he went aloft towing a glider full of magnesium and a timing device, and cut it loose to furnish light for his picture. Once a big flash bomb exploded in his plane, blowing out the entire floor, and the crew of seven had to cling to the struts until the plane landed. After many tests made in cooperation with the Eastman Kodak Company, he at last perfected the present bomb, which provides light intense enough to make a clear picture from a fast plane at altitudes well over 20,000 feet.

The Goddard bomb is a masterpiece of timing. Previous devices made it necessary to leave the camera shutter open for four or five seconds, with the result—familiar to newspaper readers—that the negative was cluttered up with extraneous fireworks, and dots of light representing burning buildings became streaks, due to the speed of the plane. Col. Goddard's problem was to produce a bomb which would crowd light of tremendous intensity into a small split-second of time. To test his flashes, he attached a sensitive photographic film to a disk record, and enclosed the phonograph in a light-proof box with a pinhole in the lid. With the turn-table revolving at a known speed, the light from the flash bomb took the place of the needle, leaving on the film a record of its duration and brilliance. This is only one example of the new methods Col. Goddard devised to perfect his invention.

The result is a bomb which crowds all its light into a fraction of a second, with a fast photoelectric cell to operate the camera within the slender margin of time. The electric eye—the same device which opens doors when a light beam is broken—is mounted in the tail of the plane overlooking the scene to be photographed. Ignoring all lesser lights from below, it is sensitive only to the peak of the terrific glare of the light bomb. Such a device has the effect of freezing motion, so that even if the plane is traveling at 250 miles an hour or more at a low altitude, points on the ground are not dragged into streaks in the photograph.

This ingenious flash-bomb device may be used by bombers as a means of securing absolute evidence of their marksmanship, and by observation planes in securing data of damage done by bombing. The timing of the flash bombs is so precise that when dropped from five miles or so above the earth, they can be made to explode within 500 feet of the altitude desired. The flash is so blinding that ground observers cannot possibly see the plane the bomb came from, yet it explodes far enough to the rear so that its glare does not overexpose the film. Many of these night photographs can hardly be distinguished from shots taken in full daylight.

Night photography for many purposes is made possible by this flash bomb. Aerial mosaic maps can be taken at night, the only limit to the size of the map being the number of flash bombs the plane can carry. And night color photographs have already been taken with excellent results.

The war's new battery of cameras includes many entries. Fighter planes have sixteen-millimeter motion-picture cameras, concealed behind small apertures in their wings, which go into action automatically when the guns are fired, and furnish a record of damage done to enemy planes. Many of the air battle sequences seen nowadays in Hollywood war dramas are the real thing, borrowed from the film records of encounters with German and Japanese fighters.

These gun cameras are of great help in teaching marksmanship. In the early stages of practice, pilots "shoot" at opposing planes with cameras, and by means of the film record, instructors detect and analyze their errors. When pilots finish their practice by shooting real bullets at "sleeves" towed by other planes, the camera often shows the reasons for misses.

Army engineers have also developed a photographic method for testing new planes. Once the test pilot jotted down performance notes on a pad strapped to his knee, but the increase in the number of instruments made this practice difficult and hazardous. Now there is a camera which takes a picture of all dial readings from a duplicate instrument panel. Meanwhile on the ground another camera, with a stop-watch in its field of vision, follows the plane as it takes off and lands, providing an accurate time-and-distance record of its ground performance.

Through a glass lightly

Another achievement of wartime optical research is the seemingly paradoxical "transparent glass." We have always thought of window glass, spectacles and camera lenses as transparent because we have had nothing better to compare them with. Actually, considerable light is lost by reflection, and glass-covered objects, like framed pictures, clock-faces and instrument dials, have always been obscured by glare when seen from certain angles. This reflection has cut down the light-transmission of camera lenses and motion-picture projectors.

For nearly half a century, experimenters have been trying to eliminate this glare in order to produce glass which is practically invisible. There have been two methods of approach: first, to etch the surface of the glass slightly with an acid, and secondly, to coat the glass with an invisible, glare-reducing film. Many firms and individuals have played a part in this work. The motion picture *Gone with the Wind* was shown on a much larger screen than usual, without loss of brightness, because glare-free projection lenses were used.

Now aerial camera lenses admit more light because they have been glare-proofed. This means sharper "vision" at greater heights, and is of particular value in night photography, when the film needs all the light it can get. Methods now exist for glare-proofing glass areas of any size, and when swords are beaten into plowshares, the public will discover how "invisible" glass can really be.

Strategists of all nations have pasted in their hats the words of Germany's General Werner von Fritsch: "The military organization with the best aerial reconnaissance will win the war." The General might have added that the country with the most alert group of photographic research men would have a distinct advantage. The best talent of American production firms and universities has been pooled to meet that challenge, and the Army and Navy, co-ordinating their efforts, have quickly utilized their best ideas and devices.

Other improvements are on the way. The flying camera will see still farther, faster and clearer, and postwar photography, both aloft and on the surface, will present many surprises.

CHAPTER THREE

THE MAGIC CRYSTAL

One morning in the spring of 1934, a dark-haired young man of twenty-five, who looked as though he might be interested in tennis and dancing, approached the desk of a Boston hotel. His only visible luggage was a bowl of goldfish, and he asked for a room on the sunny side of the house. After the bellboy had left, he placed the bowl on the window sill where it would catch the sun, stood back, inspected it, then moved it so that the reflected glare became more intense. Then he paced nervously and waited for a knock on the door.

As soon as his visitor, an official of the American Optical Company, arrived, he led him to the window and asked him to look into the bowl.

"Do you see any fish?" he said.

The man squinted and shook his head. The reflection from the water was too dazzling.

"Look again," said the young man, holding before the bowl what appeared to be a sheet of smoky cellophane. The glare was gone as if by magic, and every detail of the idling fish could be clearly seen. The visitor was convinced. He was familiar with every kind of sunglass on the market, but he had never seen anything like this. When he left, a contract was as good as signed.

So Edwin H. Land picked up his goldfish bowl and returned to his dingy laboratory in a South End basement, which was obviously no place to invite an important business man.

One of the most important optical developments of the twentieth century then got under way. The Eastman Kodak Company had already obtained a license for the use of Land's invention in making photographic light filters, and since that time the curious material has been turned to scores of diverse uses. Land founded the Polaroid Corporation, which now occupies four large factory buildings in Cambridge, employs scores of physicists and chemists, and in 1943 did a $10,000,000 business. From that smoky sheet came anti-glare goggles for the Army and Navy, and filters for all manner of military optical instruments. Because of its special construction it produces the exquisite colors of a butterfly's wings without the aid of paints or dyes, and in the path of its future lie three-dimensional motion pictures and glareless automobile headlights.

All this has been made possible because Land got his teeth into an apparently insoluble scientific problem and found a solution. Since he was a boy of fifteen working in his crude home laboratory, he had been trying to perfect a material, suitable for general use, which would polarize, or regiment light. He had read that in 1818 a French physicist, Etienne Louis Malus, looked through a piece of calcite at the windows of the Luxembourg Palace, glaring in the afternoon sun, and found that the image of the sun was extinguished. He knew that a number of natural crystals like Iceland spar and the semi-precious tourmaline behaved in the same manner, but none of these crystals could be found in large sizes, and even if they could be, they were much too expensive for any except laboratory uses.

Herapath's crystal

Most of all, he was interested in the discovery of Dr. William Bird Herapath, who in 1852 found that tiny crystals formed by combining iodine with quinine salt possessed remarkable light-polarizing properties. No phenomenon is beneath the dignity of a scientist, and these crystals were discovered when Phillips, a student of the English physicist, added iodine to the urine of a dog which had been dosed with quinine, and obtained the crystals which attracted Herapath's attention. Herapath observed that some layers of the crystals appeared to be opaque, transmitting no light at all, while others were perfectly transparent. Further observation indicated to him that all the crystals were transparent but that they became opaque when one crystal lay crosswise over another. The value of this behavior will become clear a little later.

Herapath had discovered how to make an inexpensive artificial polarizer, but he couldn't make a crystal large enough to be of any use. He labored long in an attempt to make an iodo-quinine crystal one-eighth of an inch in diameter—big enough to use as a filter for his microscope. He failed completely, and for some seventy years, so did everyone else. Not only would the crystals refuse to "grow," but they were so fragile that they would fly apart if barely touched with a piece of blotting paper.

As soon as young Land read about Herapath and his crystals, the problem became a kind of Chinese puzzle which dogged him continually, demanding a solution.

Land finally found the answer. The solution was so simple that he was amazed that no one had stumbled upon it before. He thought of the years he had spent in the quest, and asked himself, "Why does it take so long to learn so little?"

Here was his answer: instead of trying to make the crystals larger, as Herapath tried to do, make them smaller, make them by the thousand, align them all in the same direction, so that they will become a kind of huge, composite crystal, and imprison them in a transparent binder that will hold them that way.

But how was he to take vast numbers of rod-like iodo-quinine crystals—so small that they could not even be seen in a high-powered microscope—and point them all in the same direction? He tried all manner of methods without success. Then he got a new idea. He took a thin sheet of rubber, held it in a horizontal position and placed a pencil on it at an angle. As he stretched the rubber, the pencil slowly turned and pointed in the direction of the stretch. It seemed reasonable that if the tiny crystals, swimming in a solution, were applied to a thin sheet of transparent plastic, and the plastic sheet were stretched, the crystals would have to behave like the pencil, and align themselves, parallel to one another, in the direction of the stretch. After this, the plastic could be "frozen" so that it could not snap back, and cemented between protective layers of cellophane-like material. The plan worked, and this was the sheet which cut the sun's glare and subsequently enabled his visitor to see the goldfish.

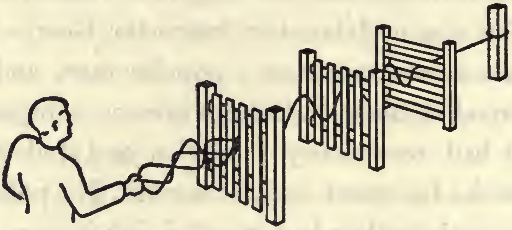
Land went to Harvard, and sat long after classes discussing his polarizer with his physics laboratory instructor, George Wheelwright. The problem was as contagious as a popular tune, and soon he had Wheelwright brooding about it. College became unimportant to them both. They both had some money, so teacher and student deserted the ivied halls, rented a basement, and got to work. The polarizer was one of a number of projects they had in mind, but it soon stole all their attention. Since that time, Land and his associates have made many improvements in light-regimentation, but his Polaroid Corporation is based squarely upon the invention just described.

It is one thing to invent a revolutionary new product; to convince business men that they should buy it is quite another matter. Land found that his excitement over the discovery was not easily communicable. After all, this was a new idea to everyone but a small group of physicists, and the product itself looked like a sheet of smoky cellophane. It could be understood only in terms of what it would do.

Land's picket fence

Simple, dramatic presentation was needed, and Land, who has a flair for showmanship as well as boundless enthusiasm for his product, was equal to the task. He used a rope trick, based on an old diagram used by teachers, to show what his invention did to light. His stage properties were three sections of picket fence, a long, thin rope and a post.

Nobody knows, he explained in his preamble, exactly how a wave of light behaves when it travels unimpeded through the air, but there is a working theory that it vibrates in every direction at right angles to its line of march, something like a Fourth of July sparkler. Since this helps to explain the behavior of polarizers as well as other optical contrivances, we may as well accept it until some scientist comes along with experimental proof to the contrary.



"Rope trick" shows behavior of light passing through polarizers. Vertical pickets stop sidewise vibrations; horizontal bars stop vertical vibrations. Crossed barriers stop all light. (Courtesy Polaroid Corp.)

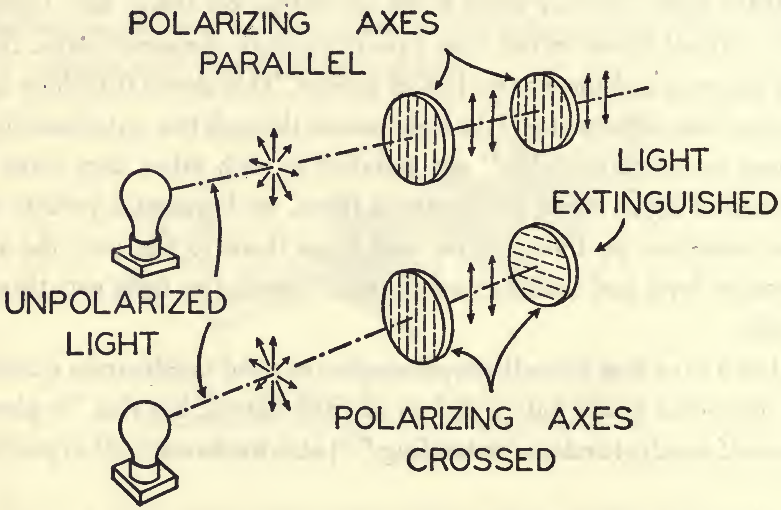
The new film takes these helter-skelter light waves and polarizes them—that is, if the sheet is held so that the fixed, invisible crystals are vertical, it knocks out the sidewise vibrations, and passes only the waves that vibrate up and down. And if you turn the sheet so that the "slots" are horizontal, it cuts out the vertical waves and passes the sidewise ones.

Then Land went into his act. He held one end of the rope and the other was tied to the post. It passed through the three fence sections. The first two sections were upright, orthodox picket fences and the third rested on its side so that the pickets were horizontal. Land shook the rope at random so that assorted waves of all kinds traveled down the line to the first fence section. This represented natural, unpolarized light. When the waves passed through the first fence, its upright, parallel pickets barred out the sidewise vibrations and passed along only the vertical ones. That is what Land's polarizer (when it is held in a vertical position) does to light. The action of the first picket also illustrates the fact that many of the original vibrations of the rope are lost in the combing-out process. This loss of energy in the rope trick illustrates the loss of intensity when light passes through the polarizing sheet. Since the sidewise vibrations are barred, the sheet cuts out about half the light. Now we come to the second picket fence, also upright. The vertical waves in the rope pass through in the same shape. Nothing happens and there is no loss of energy. This shows that there is no further loss of intensity if the light passes through two polarized sheets whose microscopic "slots" are parallel to each other. But when the simulated light waves hit the third fence, its horizontal pickets stop the vibrations in their tracks, and from there to the post the rope remains level and undisturbed. In other words, no light gets through at all.

Land says that like all simple analogies used to illustrate scientific theories, this one is only a stab at an explanation, but that "it gives a sense of comfort and understanding." It also works out well in practice.

Windows that control light

In the swank observation lounge car of the Union Pacific streamliner, the *City of Los Angeles*, one can see how the picket-fence analogy applies. This car has twenty-nine circular "variable density" windows which need no shades. Each has two panes of glass. The outer one is fixed in the position which eliminates reflected glare light; the inner one can be rotated by turning a control knob. Each pane contains one of the Polaroid "picket fences," sandwiched between layers of glass. Sit before the window and you will observe that when the rotating pane is set at a certain point, a maximum of light is admitted. This means that the two polarizing sheets are arranged in parallel, like the first two fences in the rope trick. The glass looks slightly dark, because it absorbs some of the light passing through it. Even when fully "open," this window cuts out the reflected glare of the landscape. Turn the knob slightly and rotate the inner pane, and as the "pickets" cross each other at a slight angle, the overall brightness of the sky is reduced, and details of the scenery, no longer glare-struck, become much clearer. Keep on turning the knob until the pickets are at right angles to each other, and just as the horizontal fence in the demonstration kills all the movement of the rope, the two panes now bar all light waves—in other words, the window turns black.



With double-paned polarizing windows, volume of light is regulated by rotating one of the panes. (Courtesy Polaroid Corp.)

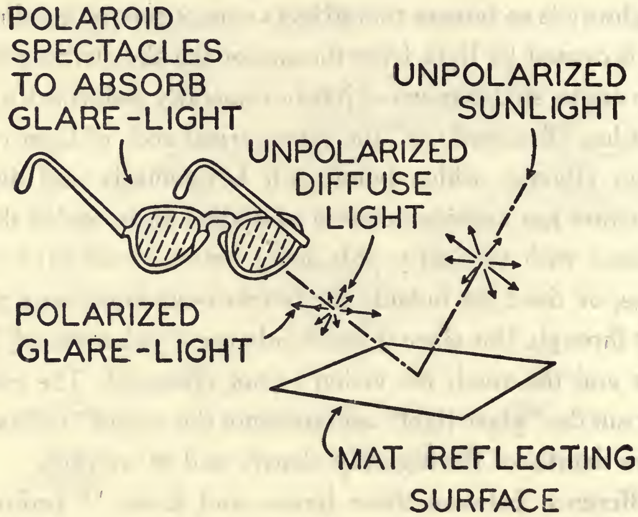
Thus Herapath's "blackout" experiment with the two small crystals of iodo-quinine is duplicated commercially with polarizing sheets which cover a large area. Similar light-regulating windows are a feature of the blueprints for a giant airliner to be built by the Consolidated Vultee Aircraft Corporation after the war. This device offers a quick solution wherever easy manual control over the intensity of light is desired. For instance, it has been used experimentally over the lenses of motion-picture cameras to provide smooth fadeouts.

This is one of the simpler of the many uses of the film which regiments light. It is also used to offset the uncomfortable effects of light which is naturally polarized. For Nature often produces polarized light, although we do not recognize it as such. When reflected light from a highway is so intense that drivers cannot see the road markers, the glare is caused by light from the sun or the sky striking the pavement at an angle, so that much of it is horizontally polarized, as though the impact has "flattened out" the symmetrical rods of light radiation into narrow ribbons, which bounce off horizontally and dazzle the eyes. So nature has provided one set of optical slots, and if the driver wears glasses with vertically polarizing lenses, these rays (like the rope waves, or the light outside the blacked-out lounge-car window) cannot get through. But since there is only one "picket fence" between the driver and the road, his vision is not obscured. The polarizing lenses bar out the "glare light" and transmit the useful "diffuse light," and he sees details of the highway clearly and in comfort.

The difference between these lenses and those of ordinary sun glasses is that the latter darken the entire view—both the rays that glare and those that illuminate—while polarizing lenses kill most of the reflections and very little of the diffuse light by which the driver sees the road.

Glasses with vertically polarizing lenses behave in the same way when used by fishermen, yachtsmen and the Navy to cut the glare on the surface of water. Just as the goldfish could be seen beneath the surface in Land's original demonstration, fishermen can see their quarry rising to the bait, and shoals just beneath the surface become visible when the blinding glare is gone. The newest development in polarizing glasses, particularly useful for peering into the sun to spot a descending divebomber, are the double-lensed adjustable ones which operate like the lounge-car windows. By turning a knob at the bridge of the nose, the wearer obtains any desired degree of light intensity.

Vertically polarizing filters for camera lenses make it possible to obtain clear pictures of water surfaces while shooting in the direction of the sun, and there are other filters for binoculars, telescopes, gunsights, range-finders and periscopes. Dermatologists and beauty specialists also use light-polarizing viewing devices to strip the glare from skin surfaces and reveal subsurface defects, and it is proposed that surgeons use them in operations to protect their eyes against light-reflections from wet tissue. With polarizing instruments, oculists can look directly into patients' eyes with no confusing glare, and polarizing screens have greatly increased the efficiency of fish inspection. The inspector sees only the fish, which has ceased to be a middleman for


POLAROID SPECTACLES TO ABSORB GLARE-LIGHT
UNPOLARIZED SUNLIGHT
UNPOLARIZED DIFFUSE LIGHT
POLARIZED GLARE-LIGHT
MAT REFLECTING SURFACE

Polarizing spectacles reduce reflected glare. Highway surface polarizes sunlight into horizontal "rods" which dazzle the eyes. Vertically polarized lenses bar this glare. (Courtesy Polaroid Corp.)

glare light that serves no useful purpose and hampers accurate observation.

If it were possible to cut the glare-making rays of natural light before it strikes the highway, or the water, most of the horizontally vibrating reflections would be eliminated in advance, and the driver or the fisherman would enjoy glare-free vision without the aid of polarizing glasses. Fitting the sun with a polarizing filter might turn out to be difficult; it is possible, however, to fit a filter over a lesser light source, like a desk lamp, stopping glare-producing vibrations at their source, and killing uncomfortable surface reflections from smoothly finished papers and photographs. This was one of the first uses of Land's invention.

A fascinating variety of useful tasks can be performed by placing the picket fences in various positions and at various angles. Suppose a light-proof anteroom is desired for a photographic dark-room, a television studio, a motion-picture auditorium or perhaps a night nursery or sickroom. Suppose you would like transparent glass doors, or glass walls, on both sides of this anteroom, so that vision is unimpeded between the inner chamber and the anteroom, and also between the anteroom (or lobby) and the corridor or street outside. Such a "light-lock" can be made by using glass which contains a polarizing filter. If the two glass doors polarize at right angles to each other, light may pass freely through either, but not through both. As you approach the outer door, you can see everything in the anteroom, but the inner door appears black. Likewise from the inner chamber the anteroom is visible, but the outer door is black. From the anteroom itself you can see through either door.

A similar arrangement has been proposed for apartment-house windows facing inside courts. If windows on one side polarize vertically, and those on the other side horizontally, outside light is admitted to all rooms, but it is not possible from one window to see through another on the opposite side.

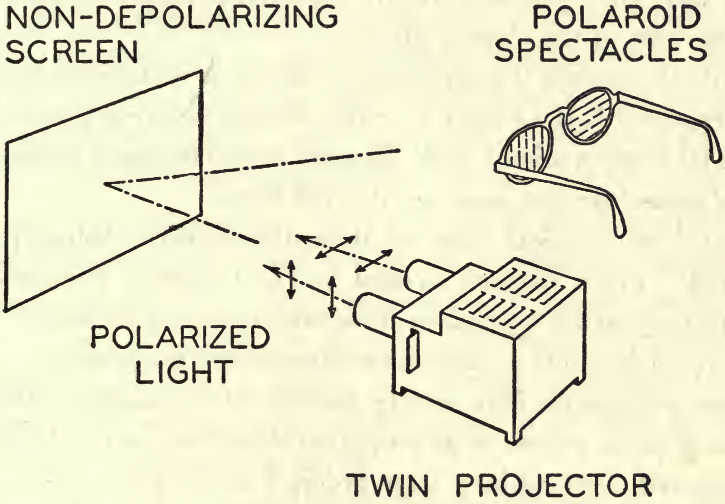
Movies "in the round"

As an introduction to one of the most dramatic wartime uses of Land's polarizers—so-called "three-dimensional vision"—we will go back a few years to a scene in an oculist's office. The patient was a woman who had been involved in an accident, and was suing for $50,000 to compensate her for the loss of sight of one eye. The glasses which the doctor gave her for the test had a left lens which polarized vertically, while the right lens polarized horizontally. He projected the usual letter-chart on the screen, and filtered the rays, first horizontally, then vertically. When the vertical filter was used, the letters could be seen only through the vertical lens—they were invisible to the other eye, since the light would not pass through two crossed polarizers. It took only a few changes of the filters to discover that the alleged blind eye was normal, and the claim was a fake.

This leads us to the fact that *by means of polarizing lenses the two eyes can be made to see different images prepared especially for them, and each lens will bar out the image intended for the other.* This is simply an elaboration of the picket-fence analogy. A device of this sort is all that is needed to create the illusion of depth in motion pictures or stills. As explained in a previous chapter, we see objects in the round because we have two eyes which observe them at different angles and automatically compare notes.

The first Polaroid motion picture to attract wide attention was shown at the Chrysler exhibit at the New York World's Fair, and the illusion was so compelling that more than one spectator tried to walk around the automobile on the screen to examine it more closely. The picture was taken on two separate films—one for each eye—by means of a double camera with lenses about three inches apart. The films were projected synchronously through dual lenses, one of which polarizes vertically for the left eye, the other horizontally for the right eye. Without special glasses, the picture on the screen was an illegible jumble, but with the cardboard-framed viewing glasses, each eye saw the picture that was meant for it, and the optical nerve center received the impression obtained when the eyes are focused on a solid object.

This development made three-dimensional pictures in the movie theatres entirely possible from an engineering point of view, but since dual projectors would be needed, it would cost exhibitors hundreds of millions of dollars to adapt their equipment. Edwin Land, working with Joseph Mahler, set to work to simplify the process, and emerged with what is known as the "vectograph," a completely new device by which both right- and left-eye images are contained in a composite film which may be shown through a single standard projector.



By separating right- and left-eye images, as in natural vision, polarizing lenses and spectacles give audience illusion of seeing pictures "in the round." (Courtesy Polaroid Corp.)

Three-dimensional vectographs went to war before their peacetime possibilities could be explored fully, and they are now widely used both in the field and in training courses. A 3-D vectograph film is made by taking a pair of stereoscopic negatives (two shots of the same object taken from different angles) and printing them on the same kind of film used for making color prints, so that the pictures appear in relief on the gelatine surfaces, with the gelatine thin where the picture is to be light, and thick in the dark areas. These relief films are hinged at the top, and soaked in a polarizing solution, the final vectograph film is slipped between them, and the sandwich is put through a clothes wringer and squeezed until a picture image is transferred to each side of the final film, with each picture a partial polarizer to correspond with one lens of the viewing glasses.

While the process is complicated in theory, it is simple in practice. It takes about half an hour to make the first print, and succeeding copies take only a minute each. As many as two thousand vectographs can be made from the same set of relief films.

Thus "the classical idea of three-dimensional photography is achieved," writes Richard Kriebel in *The Complete Photographer*, "two pictures in the same place at the same time, one for each eye, for the brain to fuse into a single three-dimensional impression."

These vectograph films can be backed with aluminum paint and used as durable prints, or as projection slides they can be thrown on a screen and observed by a large group. For either use, glasses with appropriate polarizing lenses are needed. In examining one of the backed vectograph pictures, one gets the impression of looking into a deep, glass-topped case at a wonderfully accurate scale model of houses, trees and hills. It is easy to believe that a Naval commander off Munda, using one of these films, was able to gauge the height of a hill so closely that he could aim his guns to knock out a Japanese emplacement.

An aid to teaching

The educational value of vectographs projected upon a screen and seen by an entire class equipped with the viewing glasses is obvious. Prof. John T. Rule of the Massachusetts Institute of Technology, a pioneer in this teaching technique, has developed a method for using three-dimensional pictures of models of the heavens and the earth to train navigation students. A projected image of the earth is so realistic that if an instructor walks into the beam of light, he appears actually to be walking into the center of the earth. When students look at the simulated night sky, the relative positions of the stars and earth are immediately apparent.

Before this technique was introduced, instructors tried to teach students to read depth into chalk drawings on a blackboard, and some students who were otherwise smart could never get the knack of it. The celestial vectographs, says Prof. Rule, "teach students, easily, to see and think three-dimensionally." He has used the method with success in teaching solid geometry, and it lends itself readily to other subjects. The molecule, for instance, is customarily represented in textbooks by means of a two-dimensional drawing, and many casual students leave school with the hazy idea that this all-important building block is flat, like a ribbon. Vectographs of molecular models, projected on a screen, would quickly dispel this illusion by showing the atomic arrangement in depth.

By now it should be clear that Mr. Land's invention has a vast repertoire of neat tricks. Here is another: Two entirely different pictures can be printed on a vectograph film, and one can be faded into the other simply by rotating a polarizer in front of it or by whirling a field of polarized light behind it. "Before and after" treatment is indicated. Slum sections, before and after redemption, could thus be shown, or wounded men before and after plastic surgery. And advertisers will doubtless seize upon this new way of demonstrating the astounding virtues of a pill or hairwash.

The future of three-dimensional motion pictures in the big entertainment houses belongs in the field of postwar speculation. The war halted plans for production of vectograph movie film, so we may expect it when peace comes. One may presume that if home television threatens to empty the theatres, Hollywood will seek new lures, and one of them may be the illusion of the actual physical presence of current favorites. However, vectographs probably will first be used in travel, industrial and educational pictures—all subjects in which depth of view will serve a functional purpose.

Another fair prophecy is the home vectograph album, with the usual family and vacation snapshots "in the round." There is a simple device containing mirrors which can be attached to the lens of any small camera to "split the beam" so that the two pictures necessary for making a vectograph can be taken on a single film.

Color without pigments

If you rip the cellophane from a pack of cigarettes, place it between two polarizers and hold them before a light, the cellophane blossoms vividly in all the colors of the rainbow. Turn one of the polarizers in a quarter-circle, and the colors change to their complementary hues. Give it another quarter-turn, and they change back again. These are spectacular colors, like the ones you see in soap bubbles, or the ones made by an oil slick on water. For among the other properties of Land's magic sheet is the ability to break white light, which is a combination of all colors, into the subtle hues of the "interference spectrum"—not to be confused with the raw colors of the simple spectrum.

This ability has not gone unused. Before Pearl Harbor halted the manufacture of frivolities, a number of girls with scientific training sat in a New York drafting room cutting and sticking together pieces of colorless Scotch tape. The design was not much to look at, by itself, but when placed between circular polarized sheets, and illuminated, it was transformed into a gaudy peacock. Propelled by a small electric motor, one disk slowly revolved, and the bird's plumage changed color four times with each revolution. Mounted as decorative panels in

10,000 juke-boxes, these devices spurred the jitterbugs, and gave many an idea to impresarios of theatres and night clubs. Earl Carroll, for instance, had an idea of dressing showgirls in cellophane and then shining polarized light on them, but never got around to it.

Of more interest to the scientist and the artist are the magnificent and phantasmagoric arrangements that may be seen by placing various chemical crystals between the illuminated polarized sheets and making microphotographs of them on color film. Colorless by themselves, the crystals are transformed into dazzling vistas suggestive of some unearthly jungle, or the dreamland of a mad artist. Designers searching for new motifs would do well to explore this polarized wonderland.

This color-making property has also been turned to many workaday jobs. If there are strains in transparent materials like glass and certain plastics, the strained areas appear colored when seen by polarized light. So manufacturers use polariscopes designed for the purpose to test bottles and other glass objects for the strains which show defective annealing. The builders of Boulder Dam had miniature models of the gates made from transparent bakelite, and were able to determine the exact distribution of stress by observing the behavior of the wavy, colored lines which appeared beneath the polariscope as the load was built up. When a tool-manufacturing firm had trouble with failure of saw-teeth, they made a bakelite model of the saw, subjected the teeth to the type of pressure which saw-teeth must withstand, and discovered by the telltale colored lines where the load was greatest. The same method is used in designing naval vessels. By determining what parts need to be strongest, weight and materials are saved in other parts of the ship.

With the adoption during the late 30's of all these uses of Land's sheets of imbedded quinine crystals, the Cambridge manufacturer soon found himself one of the largest non-medical buyers of the Java fever drug. As early as 1931, when the Japanese invaded Manchuria and began to cast covetous eyes southward, Land warned his associates that our supply of quinine was by no means assured, and started experimenting with new light polarizers in which the crystals from cinchona bark would not be needed. He found that a micro-crystal made from another chemical would do the job, but this did not satisfy him entirely. He finally produced a completely new type of light-polarizer, in which the molecules of polyvinyl alcohol (from which a transparent plastic is made) in combination with iodine, form long, parallel chains, or polarizing "pickets," which take the place of the needle-shaped crystals of iodo-quinine. In the process of manufacture, the plastic sheet is heated and stretched until it is three to eight times its original length. This aligns the molecules in the direction of the stretch. The basic materials of this non-crystalline molecular type of polarizer are coke, lime, air, water and iodine, all plentiful commodities.

By-product: synthetic quinine

As a direct result of this fresh invention, Land was completely independent of the cinchona groves when the Japanese took over Java. As an indirect result of his campaign to free his product from the domination of quinine, there occurred in the spring of 1944 a chemical miracle which may eventually rank with the discovery of sulfa drugs and penicillin in its value to the human race.

In considering substitutes for natural quinine, it was inevitable that Land should weigh the possibility of synthesizing the drug. For some ninety years, scientists have been trying without success to reach this goal, which had become a kind of Holy Grail for aspiring chemists. In 1856, the eighteen-year-old William Perkin spent his Easter vacation in his attic laboratory in London trying to duplicate in a test tube the quinine that comes from tree bark. Before the vacation was over, he had discovered the first coal-tar dye and founded the organic chemical industry, but he had not synthesized quinine. He had simply put together the fifty-two atoms which make up the quinine molecule, hoping that in some way they would arrange themselves correctly. He might as well have thrown a galley of type from his attic window in the fond hope that it would set itself up in a five-star final when it hit the street. Later Herman Rabe determined the complicated molecular structure of the quinine molecule, but actual synthesis eluded all laboratory adventurers.

So things stood until April, 1944, when two young chemists in Land's employ also spent their Easter vacation in a laboratory, and for the first time in history produced quinine—not a substitute or an approximation, but quinine itself—without the aid of a tree.

Land knew that the success of such a project depended, not upon money or good intentions, but upon finding a chemist with a brain like Pasteur's or Ehrlich's. He found such a brain behind the keen, bespectacled, Boston-intellectual eyes of Dr. Robert W. Woodward, twenty-seven-year-old teacher of chemistry at Harvard who had acquired his Ph.D. at the age of twenty. Research plays an all-important part in Land's business, and, like many manufacturers, he keeps on his payroll a number of part-time consulting chemists. If one of these men has a pet project which looks promising to Land, he sometimes tells him to go ahead with it on the company time, even if the project doesn't look like an immediate money-maker. One of these consultants was Dr. Woodward, who had played a part in making the new quinineless polarizer. He couldn't get synthetic quinine out of his mind, and drew up a plan for constructing the complex molecule from chemicals which may be derived from coal or petroleum. He asked for the help of the twenty-six-year-old Dr. William E. Doering, a Harvard graduate student, and Land employed him. Laboring mightily for fourteen months, this team of chemical architects duplicated the quinine molecule, capping their weary grind with a "Q.E.D." on April 10, 1944. They not only found a way to synthesize quinine, but also quinidine, a related drug, now very scarce, which is indispensable in the treatment of certain heart ailments. And in the course of their work, they discovered more than a dozen new alkaloid drugs of untested medical value, one of which may turn out to be superior to quinine in the treatment of malaria.

It will be years before this discovery can be finally evaluated. It is not yet known whether man-made quinine can be produced at a cost which will make it available to malaria sufferers. Meanwhile, this scientific triumph serves as a good example of the possible by-products of enlightened industrial research.

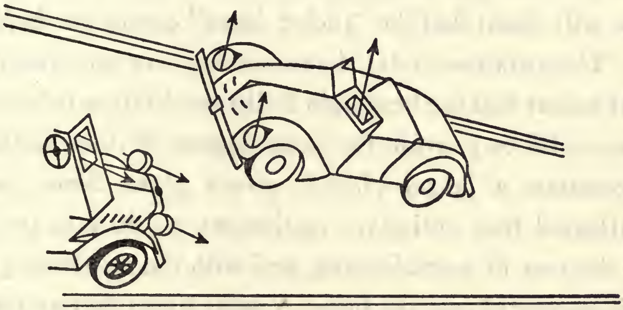
Glareless night driving

To return to Land's new molecular polarizer, it has brought closer to realization a boon which automotive engineers and highway safety experts have been brooding about for a quarter of a century—relief from headlight glare in night driving. The increase in highway speeds, in spite of improved brakes, has greatly lengthened the distance needed for stopping after the brakes are applied. This, in turn, has necessitated stronger headlights to increase the driver's range of vision. This would be fine if all cars traveled in the same direction, but one of the greatest modern traffic hazards is that paralyzing moment when two blinded drivers steer by dead reckoning and consign their souls to God. The use of a light-polarizing material is the only known way to curb this anti-social menace.

"What far-sighted physicists have long appreciated," writes Land, "was that if the headlight lenses and windshields could be made of optical 'picket fences' with the pickets parallel to each other, and at, for example, forty-five degrees to the road, the headlight problem would be solved. For it is apparent that each driver would see his own light as it illuminated the road, because the rays reflected by objects illuminated by his headlights would pass through his windshield;

whereas his windshield would have its optical slots crossed with those of an approaching headlight."

When Land, as a boy, first heard of Herapath's fragile little crystals, he began to speculate about the elimination of headlight glare, and soon found that others were thinking along the same lines. Once a research scientist of an automobile firm thought of it, and asked Prof. Robert W. Wood, the leading American authority on physical optics, the non-committal question: "Can you prepare an extensive area of Herapathite?" Wood replied tersely: "I am extremely sorry to inform you that I do not know how to make a polarizing windshield."



Headlight glare can be eliminated by placing polarizing sheets over lamps and windshields. (Courtesy Polaroid Corp.)

Soon after World War I, Lewis Warrington Chubb, now head of the Westinghouse Research Laboratories, and Lt. Frank Short of the U. S. Army, applied separately for patents on polarizing methods for dimming headlights. Later they combined, and since Land had gone farther than they, sold out to him.

For many years Land has been perfecting his method in co-operation with automobile research men, and today all the engineering tangles are being smoothed out. Tests have gone far beyond the laboratory stage. Night after night, cars equipped with the "slotted" lamps and windshield visors have met and passed at high speeds on lonely roads. When seen by the driver through the crossed polarizers, opposing headlights appear as dull, bluish spheres. Details of the bumper and hood of the oncoming car are clearly seen, and it is even possible to read the license number. Of equal importance, the dangerous pocket of black to the right of the car has disappeared, and a pedestrian, stalled vehicle or highway obstruction in this blind spot is now visible. While this does not in itself solve the glare problem for the pedestrian or the filling station worker, he can obtain the same relief by wearing spectacles with diagonal optical slots like those of the windshields.

Before Land invented the new molecular polarizer, he succeeded, after overcoming a number of difficulties, in producing quinine-crystal sheets which would kill headlight glare. But there were drawbacks. The reader will recall that the "picket fence" combs out half the light vibrations. The quinine-crystal sheets combed out and absorbed even more. That meant that the headlight bulbs would have to be more than twice as powerful to provide the same degree of illumination, which would necessitate a larger electric power plant. Some automobile people estimated that anti-glare equipment would add perhaps five dollars to the cost of manufacture, and with the customary write-up, the refinement would cost the buyer several times that amount. Automobile manufacturing costs are figured to a fraction of a cent, and sales prices are closely geared to the income of the average driver, so many pre-war automobile men shook their heads and said that "price-wise" the anti-glare equipment was not feasible. Another deficiency of the early polarizing sheet was its lack of resistance to long exposure to sunlight. In most uses this did not matter, but in a headlight lens or windshield visor it was something to consider.

The new molecular sheet does much to meet these objections. It does not deteriorate under sunlight, it is less smoky in appearance, and it transmits one-third more light than its predecessors.

Many a gaudy prospectus has been printed of the highway pleasure dome of "tomorrow." Some of the suggested features may be useful; others are only advertisers' loose promises of pie in the sky for those who suffer the privations of war. But here is a device which, if universally adopted and added to automobile equipment at a reasonable price, would not only contribute to genuine comfort and save eyesight, but would wipe out one important cause of America's stupidest crime—highway slaughter. This, when it comes, will outweigh in the scale of social value all other uses of the sheet that regiments light.

CHAPTER FOUR

THEY CALL IT FLUORESCENCE

Many years ago there lived in Bologna, Italy, a cobbler named Vincenzo Cascariolo, who pursued the interesting hobby of alchemy. One day on an expedition to Mt. Pesara, he found a heavy rock which sparkled beneath the sun with an unearthly brilliance. Greatly excited, he lugged it home and heated it in his furnace, hoping that it would enable him to produce gold. It did not.

Three hundred and forty-two years later, in the spring of 1944, the writer talked with a man in Bloomfield, N. J.—a scientist, not an alchemist—who had brought another rock back from the mountains. Beneath ordinary light it was a drab gray stone which no one would look at twice. But in the darkness, under ultra-violet light, it burst into a mass of exuberant red, flecked with spots of vivid green. In the last few years, dozens of men like him have been bringing home rocks, natural and synthetic, grinding them up, causing them to emit weird hues, and doing all manner of things with them that the old cobbler never dreamed of. And where Cascariolo failed, they have succeeded, producing wealth that would have made the old man dizzy.

They call this peculiar behavior "fluorescence," a word that will do as well as any other. The name was first used because fluor spar is one of the long list of substances which emit light of various specific colors when stimulated by certain wave-lengths from a part of the spectrum which man does not ordinarily use. The cobbler's curious find sparkled as it did because the ultra-violet part of the sun's rays evoked its fluorescence; had he possessed the equipment of our modern laboratories he would have been even more astonished by its brilliance.

Armed with invisible ultra-violet light and varieties of materials which fluoresce, physicists and illumination engineers are playing a fascinating game these days. From an array of bottles they pour little mounds of powder on a bench—powders which are all white under daylight or ordinary lamplight. When the "black light" is turned on in the dark laboratory, each mound glows with its own characteristic fluorescence color, and the experimenter is confronted with a dazzling rainbow spectacle of pastel blues, greens and yellows. For the familiar color of an object which happens to possess fluorescence has no relation to its hue when stimulated by ultra-violet. We call a fresh egg white or brown because it looks that way under ordinary light. Under ultra-violet of the right wave length it has a reddish glow. And the difference does not stop there. The light which comes from an object under daylight is only a reflection, but a fluorescent object activated by ultra-violet becomes an extraordinarily efficient converter, or middleman of light, on its own account. Because of this property, the black magic of 1602 is a modern tool which within a single decade has become indispensable in industry, commerce and scientific analysis. "Fluorescence," which yesterday was an obscure and poorly conceived word used only by physicists, is now on everyone's tongue, and there is hardly a street in America where its effect is not visible.

World's Fair toy

When the big fairs of New York and San Francisco opened their gates in 1939 with their bright prophecies of a brave new world, one of the first things that impressed the visitors was a glass wand which gave out a new kind of light. At the Flushing spectacle more than ten miles of these tubes produced a soft, diffused, yet powerful illumination unlike anything that had been seen before. Glowing in many colors, they flooded the streets and exhibits with hues unrivaled in purity and brilliance, and played a major part in creating the atmosphere of a futuristic wonderland.

What people saw was the public unveiling of fluorescent light, the first radical departure in illumination since Edison's invention of the filament electric bulb. Dazzled by the glittering parade of novelties, spectators dismissed the luminous tube as only another new toy for the decoration of fairs and carnivals. In this opinion they were not alone. Even many lighting experts who recognized the revolutionary nature of the new light believed that it would be used only for advertising and display, like the neon sign. All doubters were caught off-balance, for since that time fluorescent lighting has swept the country in a boom of amazing proportions. In war factories, offices, shops, department stores, drug stores, restaurants and fighting planes, the lamps are being installed as fast as they can be made.

And this is only one phase of the fluorescent boom. The active principle of the lamp has been adapted to a score of important uses. It has given pathologists a valuable new weapon in the study of disease; it saves the crops of potato farmers, detects mould and adulteration in foodstuffs, and has a multitude of combat uses where "seeing in the dark" may save lives.

The new lamp uses a completely new method for converting electricity into light. It has no filament, like the ordinary light bulb. Mercury vapor in the tube gives off ultra-violet light when the current passes through it, and the ultra-violet, striking a chalklike chemical coating with which the tube is lined, is converted into light suitable for illumination. It is pleasanter, cooler, easier on the eyes, and vastly more efficient than any other light ever invented for general use.

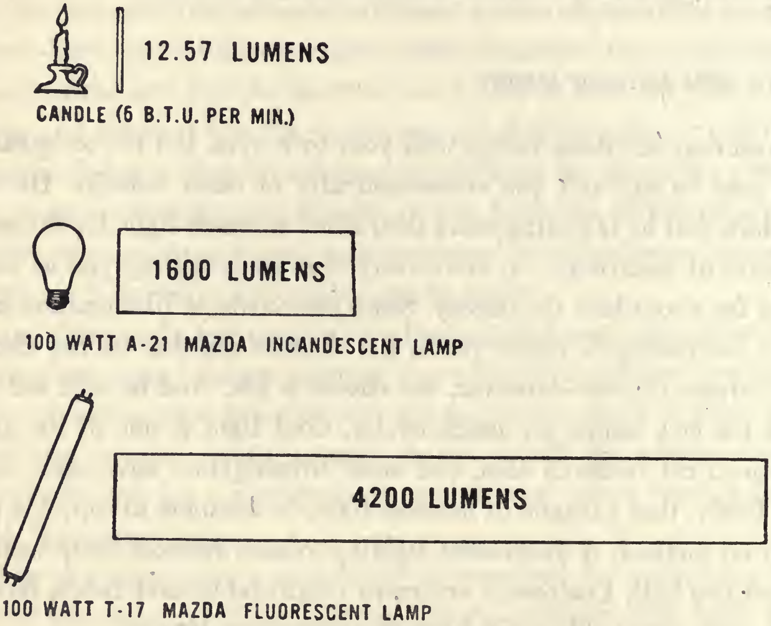
In offices, stores and restaurants, the quality of the new light is quickly noticeable, for every corner of the room appears to be flooded with soft, evenly distributed light. Overhead in clusters, or perhaps fixed vertically on the walls, are the gleaming tubular fluorescent bars, sometimes bare, sometimes partially shielded with grids made of glass or a translucent porcelain-like plastic. In either case you can look at the tubes without hurting your eyes. You will notice that, like Peter Pan, you have lost your shadow. This is because the sharp "point lighting" of the ordinary bulb has been eliminated. The tube has ten times the surface area of a regular light bulb of the same wattage, so the light is spread out as evenly as melted butter on a piece of toast.

More light for your money

You may see these things with your own eyes, but if you speak to the user he will tell you enthusiastically of other benefits. He will explain that he is getting more than twice as much light for the same amount of electricity, or, conversely, that he is getting just as much light for about half the energy. Since standards of illumination have been increasing in recent years, the chances are that he has chosen the former course—however, the choice is his. And he will tell you that the new lamps are much cooler. Cool light is one of the goals of electrical research men, and some investigators have even caged the firefly, that paragon of heatless light, in attempts to copy his production method. A fluorescent lighting system reduces lamp heat by about one half. Customers are more comfortable, and foods, flowers and other perishable goods keep their freshness longer.

This peak of performance which the new lamp has reached overnight has long been the dream of engineers. For fifty years they have been making electric light by putting current through a wire filament and heating it until it glows. This method has its limitations, for even the newest gas-filled tungsten-filament lamp, the industry's greatest achievement in the incandescent field, is more of a furnace than a lamp, since it uses ninety per cent of the power to produce unwanted heat and uses only ten per cent to make the light we are paying for.

This performance may seem crude and sloppy when set down in bare figures, but we should not dismiss it without noting that through constant improvement the incandescent bulb has stepped up the efficiency of illumination twelve- to sixteen-fold since the days of the gas-mantle, that it is fifty times more efficient than the kerosene lamp, and gives better than a hundred times more light for the energy consumed than the candle.



The fluorescent lamp gives 334 times as much light for the energy used as the candle, 2.6 times as much as the best filament bulb. (Courtesy Westinghouse.)

The early carbon filament bulb, developed by Edison, produced about three lumens per watt (amount of illumination per unit of electric power), and the lamp blackened rapidly, due to the evaporation of the carbon. The introduction of the tungsten filament more than doubled the light output, but the filaments were brittle and fragile. Then William D. Coolidge found a way of making ductile tungsten which could be drawn into fine, tough wires. There was also trouble due to the evaporation of the tungsten, and Irving Langmuir, after long and complicated experiments, solved the problem by filling the bulb with a suitable gas. This advance, introduced in 1913, redoubled the bulb's efficiency.

Since then, the inside of the bulb has been coated to reduce glare and produce more even illumination, but the drive to improve efficiency has hit an apparently unsurmountable barrier—the melting point of tungsten. With each advance, the filament has become hotter. Tungsten melts at 6120° F., twice the temperature of molten steel, and the temperature of the filament in today's bulb is as close to that point as it can safely be pushed. In some bulbs, like the photo-flood lamp used in photography, the filament is much hotter, but the intense heat shortens its life. To make a more efficient lamp for general purposes, laboratory men had to start all over again on an entirely different tack.

They found the solution in the fluorescent tube, in which no such barrier exists. Its superior efficiency can easily be shown. The tube now on the market yields about forty-two lumens per watt, as against about sixteen for the 100-watt bulb. In the laboratory, its efficiency has been stepped up to sixty and better, and further progress is expected. Some engineers predict that fluorescent tubes will be made which will yield eight times as much light for the power used as today's light bulb.

To make this tube possible, able and curious men did a great deal of work between the days of the Italian alchemist and Fairmaster Whalen. The cobbler's discovery of the "Bologna stone," as it was called, created a sensation, and it quickly became the fashion among experimenters of the day to collect so-called "natural phosphors" and test their behavior under light. Word came from China of an artist who painted a picture of a bull which glowed furiously with a light of its own. Confusion arose, which has not yet been entirely dispelled, between phosphorescent substances, which, in effect, store up light in the daytime and give it out at night, and fluorescent materials which glow immediately upon excitation, and lose their glow when the exciting light is removed. It is the latter phenomenon with which we are now concerned.

In 1833 Sir David Brewster, condensing a beam of sunlight with a lens and playing it upon a test tube full of vegetable coloring matter, found that the light made a blood-red path through the green solution. He thought it might be due to red particles held in suspension in the liquid, and so coined the short-lived label, "internal dispersion."

Stokes the discoverer

Then ninety-odd years ago the eminent physicist, Sir G. G. Stokes, picked up the loose threads and tied them together for all time by means of a simple experiment. Using a piece of quartz to break up the rays of the sun into its various wave lengths, he took a test tube filled with a solution of quinine sulphate—which was known to behave strangely under daylight—and moved it slowly down the rainbow spectrum. When he reached the ultra-violet range, a ghostlike gleam of blue light shot across the tube. He had found that the curious light-changing quality of the chemical was attuned to ultra-violet; that it had the ability of absorbing light of one wave length (or color) and pouring it out in another and longer wave length. He christened this ability "fluorescence" and summed up his findings in "Stokes's law" which is the scientific foundation of all uses of fluorescence.

Like many other pioneer scientists, Stokes had no idea that his discovery was of any practical use. After he pointed the way, there was still a great deal to do before fluorescence could be used for anything except a subject for scientific papers. Investigators in Germany, France, England and the United States compiled long lists of fluorescent minerals and plant substances, and experimented with light to find out what wave lengths were most effective in exciting them.

One of the first uses of fluorescence for illumination came in 1903, when Peter Cooper Hewitt, grandson of Peter Cooper, the famous New

York inventor and philanthropist, used it to tone down the ghastly greenish light which came from the mercury arc in his "Cooper-Hewitt lamp." He placed a reflector above the lamp coated with a chemical which gave off a red glow when excited by the ultra-violet in the arc. The result was illumination similar to daylight.

Finally someone hit upon the idea of caging ultra-violet light and a fluorescent material inside a glass tube and thus making a new kind of lamp. Many people had a finger in the pie. The first fluorescent tubes were seen in Holland in the mid-thirties, but they were high-voltage lamps unsuitable for general use.

Engineers of three firms—General Electric, Westinghouse and Sylvania Electric Products, Inc., working in laboratories at Cleveland, Bloomfield, N. J., and Salem, Mass.—were responsible for the American development of the fluorescent lamp, and these firms now make ninety-nine per cent of all the tubes produced in the United States. One of the first fluorescent materials to interest these experimenters was willemite, a speckled rock found in abundance in many parts of the country, which blazes with greenish-white light under ultra-violet.

In his laboratory at Nela Park, Cleveland—the General Electric Company's "University of Light"—George Inman, who had much to do with making the new lamp, ground his willemite to powder and picked out the useless black spots by hand. He and his fellow workers mixed the white powder with an adhesive, and sprayed a thin coating on the inside of a glass tube. Electric terminals were placed in the ends of the tube, and it was filled with mercury vapor, which acted as a conductor and closed the circuit when the current was turned on. This provided a rich source of ultra-violet. It was transformed by the excited willemite into a wave length suitable for illumination, and soft fluorescent light poured forth from the tube. It was a crude affair, but gave promise.

Meanwhile in Salem, James L. Cox, a young Cornell graduate, turned from his experiments in electronics to the delicate problem of making fluorescent powders with which to coat the tubes. These coatings, which are sprayed inside the tubes in liquid form and then dried, are composed of millions of tiny particles interspersed with chinks to let the light out. Cox found a way of arranging the particles so that they formed a firm coating and yet left plenty of chinks. And Westinghouse engineers worked on other aspects of the new lamp.

These beginnings are so obfuscated by litigation that it is hard to say where most credit is due, but what is of chief interest to the consumer, the lamps were built and have been steadily improved. Rocks are no longer ground up to make the powder. Other methods have been found to produce purer materials, and scores of fluorescent powders have been developed which will react under ultra-violet to produce whatever color of light is desired. Light of various colors can be obtained simply by mixing the fluorescent powders. Powders that fluoresce pink, buff and blue will yield a white light, and by altering the recipe you can get a "daylight" which consumes only one-third of the current used by an incandescent daylight bulb.

To the scientist, there is one outstanding reason for the remarkable economy of the fluorescent lamp. Different fluorescent materials are fastidious about the exact wave lengths of light to which they will best respond, but those which give the most light are attuned to that line in the spectrum labeled "2537 Angstrom units." And by a fortunate coincidence, the lamp can generate ultra-violet of 2537A. more efficiently than any other wave length. When Einstein visited the Westinghouse laboratories, he wanted to know how much of the ultra-violet light generated in the tube was 2537. The answer was eighty-five per cent. That was the only question he asked. That figure told the story.

Before these new lamps were invented, colored light was produced by staining the bulb or using a colored screen, and as much as ninety per cent of the light was lost in the process. Fluorescent colored light is colored to begin with—the wasteful middleman has been fired. This was one reason for the immediate popularity of the lamp in display lighting. Another reason was the soft, pleasing quality of the pastel shades contrasted with the sharper glare of colored light produced by other methods.

Like all new products, the early fluorescent tubes had their imperfections. One was "stroboscopic effect," which sometimes created the illusion of making moving objects stand still. The light in the tube actually goes out 120 times a second, owing to the rapid alternation of the current, and if a revolving wheel is synchronized with this effect, the wheel may appear to stand still. This effect is seldom noticeable except in the presence of machinery, and when the tubes are installed in groups of two or more, as they usually are in plants, it is easily taken care of by having the lamp currents "out of step" with one another.

The early lamp was slow to light up, and when in its old age it began to blink and blacken, it took an unconscionable time dying. Now these hesitant habits are much less noticeable. Meanwhile, the average life of the tube has been increased to 3,000 hours and better, compared with ratings of 750 to 1,000 hours for incandescent bulbs. The longer the tube glows undisturbed, the longer its life, and some tubes which have been allowed to burn day and night for testing purposes have lasted more than a year.

The infant invention was hardly out of its diapers when it was snatched from the laboratory and set to work. In the summer of 1937, Bassett Jones, lighting director of New York's projected World of Tomorrow, went to Nela Park, Cleveland, and asked, "What's new in lighting?" He saw the glowing tubes, and nothing else would do. Orders were quickly placed with all firms which were making the tubes, and research men put on overalls and worked overtime to turn them out. Every fluorescent light which spectators saw at the opening of the fair was a laboratory product. By degrees the industry moved into the factory, and great new plants with specially designed production machinery went into operation to meet the tremendous demand. Since their introduction five years ago, well over 100,000,000 fluorescent tubes have been produced in the United States.

Better light for workers

The new lamp came along just in time to light the new war factories, where it provides the best illumination ever discovered for close mechanical work. Workers in scores of the vast aircraft and munition plants are speeding production and saving their eyes under its soft, powerful glow.

When the country launched the big armament drive, it was common knowledge that most factories were too dimly lighted for fast, accurate work. The average illumination was about five foot-candles, which is hardly one hundredth of the light you get when you sit under a tree reading on a bright day. For many years authorities had been crusading for better light, but the heavy cost of wiring for more power, as well as the prospect of higher light bills, had blocked their efforts. Now the government called for thirty-five to sixty foot-candles of light in plants which it financed. The fluorescent lamp, giving more than double the amount of light for the power, made this possible. To the machine operator it is like bringing a piece of the noonday sky indoors.

Big textile plants in New England and the South are rapidly changing to fluorescent lighting. In one typical factory, the plant engineer had added all the bulbs which the wiring would take, and the light was still so dim that eye trouble was an occupational ailment among the machine operators. Fluorescent lights were installed which doubled the amount of illumination without increasing the load on the wiring. The light bill remained the same, and the cost of the change was about one-third what the factory would have paid for rewiring.

These are a few of the reasons why the new lamp is rapidly becoming standard equipment in large American plants. The lamp's auxiliary devices make fluorescent lighting more expensive to install than the ordinary filament-bulb system, so it is still of chief interest to establishments that use a great deal of light, and in places where light of a special quality is needed. Art museums, for instance, have tried for years to duplicate artificially the north light under which painters work, and which should fall on the paintings if we are to see them as artists meant them to be seen. Now Pittsburgh's Carnegie Institute has solved the problem with fluorescent light.

The new light has spread through the nation's retail shops with the speed of an epidemic. Its coolness reduces the cost of air-conditioning in modern restaurants and department stores. Drug-store proprietors all tell the same story of better light and current economy. Many of them report slashes in the light bill of thirty per cent or better. Since they remain open long hours and often burn lights in the daytime, this saving usually pays off an installation cost of $300 or so inside of a year.

In the home

Fluorescent tubes have also become popular for many home uses. Here their economy is not very important. Since few home lights are used more than 800 hours a year, it would take years to pay for the more expensive fluorescent equipment out of savings in the light bill, so their value depends upon the quality of the light and the fitness of the tube in decorative schemes. Many tubes are now being used in bathrooms, game rooms and kitchens. Their coolness and lack of glare makes them popular over sinks and work tables.

The effect of fluorescent light upon colors is slightly different from the familiar color distortions caused by the filament light bulb. The ordinary bulb is overrich in yellow and red, while the new lamp is short on those colors and has an extra supply of blue and green. There are powders which fluoresce red, but their efficiency is so low that if used in any quantity they would greatly reduce the light yield.

This unaccustomed distortion has both advantages and disadvantages. Navy blue is quickly distinguished from black under fluorescent light, while under the filament bulb they look much the same. The yellowish filament light tends to conceal scorching caused by ironing, while the new light throws it into prominent relief. The yellow of butter takes on a faintly greenish tinge under fluorescent light, and coffee with cream may look a little muddy. The industry is meeting this problem in two ways. After careful experiments with fluorescence, fabrics and foods, they have produced a "soft white" fluorescent tube, in which a little cadmium borate, which glows pink, helps to correct the distortion, and they are waiting for people to get accustomed to the color changes. After several meals under fluorescent light, few people notice the difference.

Because they are slenderer than filament bulbs, the tubes are more practical for built-in lighting. They are so cool that they can be safely installed behind the tops of window draperies, and a number of people are using them in this manner, especially in modern interiors. Their use in period interiors is another matter. Most American rooms, still under the influence of the tallow candle, are designed for circular "spot lighting," and it would take a callous wretch to install the linear tubes in a Colonial living room. But the tubes do not have to be straight. In laboratories they have already been bent into a circle, and soon after the war, circular fluorescent tubes suitable for shaded table lamps and floor lamps will be placed on the market. Some production men are not too keen about this development because of the increased difficulties of manufacture and shipping, but one of them dourly remarks that if customers demand fluorescent tubes shaped like pretzels or tied in bow-knots, the industry can supply them.

All the lamps are now straight, and sizes run from cylinders seven or eight feet long to tubes of six inches no thicker than your finger. These pigmies are being used to light the instrument panels of war planes, and operate somewhat differently from the large tubes. The fluorescent material is not inside the tube; it is painted on the indicators and numerals of the dials, which are made legible by a beam of invisible ultra-violet coming from the masked tube. The reduced glare inside the cockpit helps the pilot's vision in night operations.

Fun for all

Since the fluorescent coating need not be confined in a glass tube, but will glow under the stimulation of an invisible ultra-violet light source many feet away, and since it can be mixed with paints, lacquers and dyes without losing this special sensitivity, and can itself be made invisible under ordinary light, there is hardly any limit to the number of fascinating tricks it will do. Experimenters have had more fun with it than a boy with his first meccano set, and many of the tricks have turned out to be useful.

A research scientist was showing me some fluorescent chemicals under invisible light in his laboratory when I noticed that across his white shirt front "B-15" was stamped in large blue symbols. When we left the laboratory, it was gone. He explained that his laundry marked garments with a fluorescent dye, since many people dislike indelible-ink markings. The man who makes up the packages sorts the garments under invisible light.

A Chicago hospital, after a lawsuit in which it was charged that babies had been shuffled, took to marking them with a harmless fluorescent dye, and can now settle any dispute with ultra-violet.

Many years ago Dr. Robert W. Wood, noted for his brilliant contributions to the knowledge of fluorescence as well as for his scientific pranks, brought forth the spectacular stage effect by which a line of chorus girls can be suddenly transformed into dancing skeletons or a row of bodiless shoes, gloves and hats. This is done by painting the costumes with fluorescent material which cannot be seen under the ordinary theatre lights. When the lights are turned out and the stage flooded with invisible ultra-violet, only the fluorescent markings are visible. Advertising billboards have used the same technique to make the same space carry a double message at night when lit alternately with ordinary bulbs and "black light." Night clubs use it. At the turn of a switch, walls which are ordinarily blank blossom forth with romantic, tropical vistas. A number of theatres have fluorescent aisle carpets, made to glow by concealed black-light sources, for the guidance of those who enter in the dark. Other suggested decorative uses, such as fluorescent wall and rug patterns activated by black light to provide a theatrical setting for home movies and television, may not be socially successful. Natural teeth glow brightly under ultra-violet, while store teeth are black, and dyed hair may look green.

Obviously, fluorescence is a useful accessory in the game of cops and robbers. A dry cleaner's fluorescent mark, glowing under black light, identified a murdered woman in Illinois, although the killer had removed all visible identifying marks, and the fluorescence of inconspicuous blood spots on the murderer's clothes helped to convict him. In several cases, the color of an automobile which has struck a pedestrian has been discovered by means of the fluorescence of minute paint particles which stuck to the victim's clothes.

The fact that different inks and glues fluoresce differently under the invisible light provides a new weapon for the detection of forgery, alteration of documents, and tampering with the mail. If a letter is pried open and glued up again, the new adhesive betrays itself unmistakably. Fluorescence used in gasoline ration stamps and the plastic ration tokens helps inspectors with a black-light lamp to detect counterfeiting. Invisible fluorescent watermarks on bank notes, blank checks and other forms of commercial documents are putting forgers on their mettle. Before the war restricted sales, a Cleveland firm was advertising an inexpensive fluorescence kit—a package of powder and a small "invisible lamp"—for the detection of petty thieves or saboteurs. If cash or merchandise has been disappearing, or if machines are being damaged, you dust them with the inconspicuous powder. No matter how long the guilty person scrubs his hands, beneath the light they will blaze with a telltale green.

Since the fluorescence colors of many materials used in painting, sculpture and ceramic art change with long exposure to air and daylight, the ultra-violet lamp often gives instant proof that a reproduction is being passed off as an original, and the expert may detect repairs or alterations because of the conspicuous fluorescence colors of new glues, paints and varnishes.

Some commercial artists are using fluorescent water colors instead of ordinary pigments, claiming that when they are photographed under black light for four-color process printing plates, the color separations are more precise and the reproduction more faithful.

Potatoes and honey

Fluorescence has many uses in agriculture, and in determining the contents and the freshness of foods. Butter and margarine may look alike under daylight, but margarine glows with a strong blue under invisible ultra-violet. Fresh eggs have a reddish fluorescence, but as they age the color begins to change through reddish brown to blue. Eggs that have been dipped in preservative are easily spotted by their changed fluorescence color. The lilac fluorescence of fresh walnuts changes to yellow as they age. Fluorescence betrays the presence of chicory in coffee, horse fat in lard, and refined oil in supposedly virgin olive oil. Put honey beneath ultra-violet light, and with a little training you can tell by the nature of the fluorescence what flower the bees fed on.

Fungus infections and other plant diseases are now detected at government experiment stations by their fluorescence. Ring rot has long been a serious problem of the potato farmer. When he cut up his seed potatoes for planting, the occasional infected spot was hard to see, and sometimes his entire crop was blighted because he spread the infection with his knife. Prof. R. B. Harvey of the University of Minnesota observed that the fluorescence color of ring rot is bright green, and worked out a technique which many farmers have used with success. When they do their cutting beneath ultra-violet, it is easy to throw out the diseased spud and dip the knife in a disinfectant.

In war production and on the fighting fronts, fluorescent materials have their ingenious uses. Manufacturers of airplane engine parts immerse them in oil, which is fluorescent, wipe them clean, and inspect them under the black lamp for tiny cracks or flaws into which the oil has seeped. A Texas prospector has devised a new method of locating oil by placing surface samples of soil beneath black light. Petroleum gases are fluorescent, and if they have been seeping upward from oil deposits, the light will show it. In the Rocky Mountains, prospectors are prowling at night with ultra-violet flashlights to locate deposits of scheelite, from which strategic tungsten is obtained. Streaks of scheelite in the rock outcroppings fluoresce blue.

Three-tenths of the energy in sunlight is in the ultra-violet band of the spectrum, and many fluorescent materials, like the Italian cobbler's magic stone, react to these wave lengths, which are much longer than those used in commercial illumination. This has led to military uses of fluorescent materials which glow vividly in daylight. The equipment of an inflatable life-raft contains a package of fluorescent powder. Thrown into the sea, it stains the water bright green over a large area to attract the attention of rescue planes. And fluorescent fabrics are made by which ground detachments may signal more easily to fliers.

For trapping bacteria

In recent years, fluorescence has become an important implement in the fields of medical research and surgery. The fluorescence microscope, which Col. Max Haitinger of the University of Vienna appears to have invented in about 1911, has now been perfected by American experimenters and is widely used in the identification of bacteria and the study of cell structure. Since Ehrlich's time, pathologists have stained sections of tissue with dyes to make them visible under the microscope. While Ehrlich's technique brought about an epochal advance, scientists have always had to make allowance for changes in appearance caused by the chemical action of the dyes. With the new microscope, the specimen is flooded with ultra-violet, and its fluorescence colors often create a more vivid, clear-cut picture than research men have ever seen before.

Dr. Hans Popper of Cook County Hospital, Chicago, former associate of Haitinger and one of the pioneers in the use of the fluorescence microscope in this country, has been experimenting with Vitamin A, which is important in the prevention of night blindness. He feeds the vitamin to rats, and studies specimens from their livers beneath the new microscope. The vitamin's green fluorescence color enables him to trace its course, and reveals facts about its behavior which are of value in treatment. The fluorescence color of Vitamin A also enables the Canadian Fisheries Research Board to determine which part of the fish is richest in the much-needed chemical, and thus helps to speed its production.

It has been found that many species of bacteria have characteristic fluorescence colors. The tuberculosis germ glows in yellowish rose; the "A-type" typhoid germ in violet-tinged yellow, and the "B-type" in greenish yellow. Cancerous tissue fluoresces with a purplish-pearly hue, in contrast with healthy tissue, which appears almost black.

The new "searchlight" is being used at the Cancer Institute at Buenos Aires to identify skin cancer, and at the Memorial Hospital in New York to identify unknown chemicals in removed cancerous tissue.

When the bacteria or tissue does not have a natural fluorescence color vivid enough for easy identification, it may be stained to induce a secondary fluorescence. This method is now used in many clinics in analyzing the sputum of tuberculosis suspects. Under ultra-violet, the stained bacilli stand out sharply against a black background. Bacteria which once had a chance of escaping detection are now trapped by their fluorescence, and the time needed for identification is cut by about one-third.

Working along different lines, Drs. Kurt Lange and Linn J. Boyd of New York are using fluorescence as a "speedometer" of blood circulation and as a means of diagnosing gangrene and circulatory ailments. With the patient lying under an ultra-violet lamp, a solution of fluorescein, a harmless fluorescent chemical, is injected in his arm, and as the dyed blood circulates through the system the skin glows golden-green wherever it penetrates. If the color cannot be seen in an injured leg, it is evidence that circulation has failed, gangrene has set in, and the leg must be amputated. The line of demarcation is so sharp that it tells the surgeon exactly where the amputation must be made. The same method is used to determine whether the circulation is still sound in a hernia so that it can safely be pushed back in place, or whether the blood stream no longer reaches it and surgery is necessary.

In plastic surgery

This technique is of particular value in wartime plastic surgery. When a tubular flap of skin, possibly from the abdomen, is grafted to an injured part of the body, it is supplied with blood from its original source until such time as circulation from its new bed is well established. By tying the flap temporarily to cut off the original blood supply and injecting fluorescein in a vein, the surgeon can tell in a few seconds from the greenish glow—or the lack of it—whether he can safely sever the flap.

By means of a more elaborate method, Dr. Lange and his colleagues are able to measure the speed of the blood stream and the volume supplied to any part of the body. A boxlike device containing an ultraviolet bulb and a phototube is placed, for example, on the patient's shin. By means of a dial, the sensitive phototube shows not only the number of seconds the injected fluorescein takes to reach the shin, but by registering the degree of greenness, shows the doctor how much blood the leg is getting. This is an accurate new aid to the diagnosis of such diseases as diabetes and arteriosclerosis.

These are only a few newly discovered uses of the strange luminosity which so long was idle, and those who have harnessed it readily admit that men of the future may regard their achievements as experimental fumblings. More uses may be announced at any time. Research men in many laboratories are testing the fluorescence of hundreds of materials, experimenting with various wave lengths of exciting energy, and trying out new ways of uniting them for all manner of tasks.

This work necessarily concerns itself with only a narrow slice of the great ether spectrum. Science has only begun to explore the long rainbow ribbon, which to man's knowledge stretches in one direction from the visible light band far beyond the infra-red and radio areas to great undulations thousands of miles in length, and the other way down past the vibrant domains of the ultra-violet and the X-ray to the crowded region of the cosmic ray whose waves are too infinitesimal for the mind to measure. And the ends of this streaked ribbon-map are not cut clean; they are jagged breaks, each with a challenging arrow pointing to unknown terrain.

PART TWO

MOTORS AND MILES

CHAPTER FIVE

THE OCTANE REVOLUTION

Back in the ancient days of 1934, a flier named James Doolittle, who had retired from the Air Corps because of "advanced years," flew a Seversky plane crammed with scores of testing instruments of his own design. He returned with glowing tales of engine performance previously unheard of, brought about by a new fuel in his tanks. Little public attention was paid to this new fuel, but even if its name had been printed in headlines, few would have recognized its significance. Doolittle had been testing 100-octane gasoline for his current employer, the Shell Oil Company. A rare and expensive hydrocarbon compound called iso-octane, which hitherto had been employed only as a laboratory yardstick for measuring lesser gasolines, had been used in making this amazing super-fuel. Now the Army had ordered 1,000 gallons for experimental use in new airplanes.

Soon ten steel drums of the precious stuff arrived at Wright Field, Dayton, Ohio. Only a few years before, it had been sold by a chemical firm in small lots at $25 a gallon, and even at Shell's price—$2.40—it was far too expensive to burn in a motor by itself. But it was so powerful that when Air Corps experts mixed it with an equal amount of the best aviation fuel of the day, and added a little tetra-ethyl lead, they brought the whole batch up to the 100-octane level, and had 2,000 gallons with which to experiment.

Only a few Army planes were equipped with motors which could digest this mighty pabulum. Their tanks were filled and they were sent aloft. Results in terms of increased performance were spectacular. Within a year the Army placed an order for a million gallons of the new fuel, and engine designers scrapped all their plans in order to build new motors which the super-fuel had made possible.

The rise of high-octane gasoline since that time is a miracle of production. In 1944 American refineries turned out more than 16,000,000 gallons of the new fuel every day. It has given Allied planes priceless advantages in speed, short take-offs, steep rates of climb, high flying ceilings and size of bomb loads. Without 100-octane fuel, states Geoffrey Lloyd, British petroleum secretary, the Battle of Britain would have been lost. Without it, the Fortresses and Liberators would labor and falter at 40,000 feet. It drives America's long-range fighter, the Mustang, at a cruising speed of 378 miles an hour, and it sent the giant new forty-ton transport Constellation from Burbank, California, to Washington in six hours, fifty-eight minutes. After World War I, Lord Curzon remarked that "the Allies floated to victory upon a flood of oil." Today they are flying to victory upon the rarefied quintessence of that oil.

The campaign of petroleum chemists to increase the "octane number" of gasoline was by no means new in 1934. Progress in gasoline propulsion for the last twenty-five years has depended upon the neck-and-neck race between motors and motor fuels. Gasoline can be improved in many ways, but the added power symbolized by octane number has been achieved by two methods: by adding a few drops of something to the fuel, and by rebuilding and blending the gasoline itself. Before 1934, the former method was largely responsible for major advances. Then it became clear that further improvements in motor design were waiting upon completely new fuels, which could not be produced by "shaking in seasoning." Complete new recipes on which the petroleum chefs spent years of labor and which cost fortunes to put in practice are responsible for the "fighting gas" which in a few short years has revolutionized the internal combustion engine. The seasoning is still valuable, but the fuel itself is something new under the sun. If you filled the tank of a Thunderbolt or a Mustang with the best fuel of ten years ago, the motor would literally burst in pieces before the plane got off the ground.

"Octane" has become a magic word, but it still remains something of a mystic word. By definition, *the octane rating of a gasoline expresses the capacity of the fuel to be compressed without detonating.* Since chemists labored for years laying the scientific groundwork for that pat phrase, and still have plenty to learn about the matter, it is not surprising that there has been much popular confusion about the mystery of the fabulous octane.

To trace the word to its lair, we must return to the great pioneer in the field, the late Dr. Thomas Midgley, Jr., the discoverer of the gasoline additive, tetra-ethyl lead. At a meeting of the American Chemical Society a few years ago, Dr. Midgley, who was recovering from an attack of infantile paralysis, was pushed forward in a wheelchair to receive the greatest honor which the Society can bestow—the Priestley medal. Instead of making an acceptance speech, Dr. Midgley turned to a small, one-cylinder gasoline engine at his side. It had two glass fuel tanks, mounted in plain sight. One held a water-white gasoline—the other a reddish mixture. The mixture contained an eye-dropper quantity of tetra-ethyl lead, a chemical made by subjecting metallic lead to the action of a gas. It is a liquid which looks like water, and the mixture was colored only for the purpose of identification.

The engine was started on the colorless fuel, and soon the auditorium rang with a sharp "ping-ping-ping," so distressing that many of his hearers fought an urge to reach for the gear-shift. Then a lever was turned, and the gayly tinted liquid was fed to the complaining motor. Its cries of anguish subsided, and it purred like a kitten full of cream.

The applause was prolonged, for Dr. Midgley had demonstrated his greatest accomplishment—the use of tetra-ethyl lead to keep an engine happy. The silencing of that knock affects everyone who drives a car, for the modern automobile is what modern fuel has made it. Not only the fast getaway, the surplus horsepower, the swift glide up hills, and the greater mileage per gallon, but the stronger, safer steel body, and other weight-adding refinements like radios and heating systems, have all been made possible by the creation of gasolines that motors will swallow without gagging, and by the radical new engine designs which these fuels have brought about.

When Dr. Midgley solved the mystery of engine-knock in 1922, the best cars on the road were feeble, coughing gas-buggies compared with the compact, responsive mechanism that modern drivers take for granted. Since that day, engine performance has been boosted by fifty per cent and miles per gallon by twenty per cent, and the amount of petroleum normally needed to make America's peacetime motor fuel has been cut in half.

The great detonation mystery

The knocking of an engine under strain was a great mystery when young Tom Midgley, a mechanical engineer a few years out of Cornell, got a job with Charles F. Kettering during the early days of the World War. Some engineers blamed the carburetor, some the battery, and some the new self-starter which Kettering had developed. There were a dozen mechanical theories, all of them wrong. No one suspected that the fuel was the villain, and least of all did anyone perceive that the entire progress of transportation was marking time until someone mastered that irritating "ping-ping-ping."

Kettering was having knocking trouble when Midgley came to work for him at Dayton. His small Delco engines, which drove farm lighting units, ran on kerosene, and under full load they knocked badly. He asked Midgley to see what he could do about it. Midgley noted that when gasoline was used as a fuel, the knocking ceased. He installed a special recording device to enable the two fuels to write their own diaries, so to speak. Their record cards convinced him that engine knocks were caused by the nature of the fuel used, and that it was possible to get rid of excessive knocking by some change in the composition of the fuel. He had hit upon the right theory, but he was still far from being out of the woods. To prove his theory, he wanted to see with his own eyes the explosion inside the cylinder. He had a two-inch hole bored through the side of the combustion chamber, and set in a pane of glass. The glass broke under the heat, and he replaced it with more durable quartz. For the first time, an engineer had a ringside seat at the internal combustion engine's knock-out battle of oil and fire.

Watching the play of flame through his peephole, Midgley got another hunch. This hunch was completely wrong, but it led to the right answer. He saw that when the engine ran evenly on gasoline, the flame was blue; when it knocked on kerosene, the flame was white. At that point, he shut down the motor, went to the chemical stockroom with a flask of kerosene, and asked a question which has become a legend among technical men.

"Fred," he said, "have you got any oil-soluble dyes?" He explained that he wanted to dye the kerosene a darker color. He had an idea that a darker color might absorb more heat and do away with the knock.

"No," said Fred Chase, completely unaware of his historic responsibility. Then his eyes wandered over the shelves. "Here's some iodine," he said; "you might try that."

It was a miraculous choice. Out of some 10,000 bottles on the storeroom shelves, only one contained a material that would stop an engine-knock. That was iodine. They dropped some crystals into the flask of kerosene, and the liquid turned to reddish purple. Midgley started the engine once more, and fed it the same fuel which made it protest bitterly. The same fuel—plus a few crystals of iodine. It worked like a charm. The knocking stopped.

The next day he obtained a number of soluble dyes from another laboratory and quickly found that color itself had no effect whatever upon knocking. It was a peculiar property of iodine. It was his good fortune that there had not been a single oil-soluble dye in the storeroom. He would have tried it and abandoned his idea, and years might have passed before any experimenter discovered the secret.

Experiment 15,000

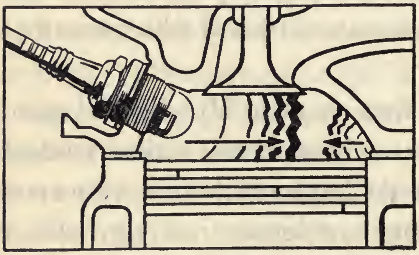
Midgley had made the exciting discovery that a few drops of material added to motor fuel would control knock, but that was only the beginning. Iodine was too expensive for commercial use and otherwise inadvisable. Trained as a mechanical engineer, Midgley learned chemistry on the run. Installed in an old dwelling house with a dozen helpers, he plunged into an orgy of scientific detection, for he never doubted that if iodine would stop knocking, other chemicals existed that would do the same thing. It has been estimated that Midgley performed 15,000 experiments in his search for a cheap, effective antiknock substance. Some of them took a few seconds; some several weeks. For a time, tellurium looked promising, but it had a violent garlic odor that clung to everything, and for six months Midgley and his men were social outcasts. Tellurium was abandoned, which was probably just as well. When they started the test engine for the 15,000th time, they knew they had found the answer. The fuel contained a few drops of the compound called tetra-ethyl lead. It was the best antiknock agent they had found, and its ingredients were abundant and low in price.

Perfecting this fluid meant more work, and before the job was over Midgley left his laboratory and took up the quest at sea. He found that while the fluid stopped knocks, the lead oxide which remained after it burned was bad for the engine. Another chemical had to be found which would counteract this effect. Bromine worked out well, but the supply from brine wells was only a fraction of what would be needed. Everyone knew of an inexhaustible source of bromine—the sea. It had never been done before, but the Midgley forces were determined to tap this rich reservoir. Boarding a ship christened *Ethyl* they spent a month experimenting off Wilmington, North Carolina. As a result, they teamed up with the Dow Chemical Company to build a big plant at Wilmington for mining the sea. Bromine is also obtained at the plant built recently on the Texas coast for the recovery of magnesium from sea water. Bromine production has pyramided since that time, and nine-tenths of it is used in Midgley's anti-knock discovery. With the addition of bromine to the fluid, Midgley finally reached his goal. Before the war, it was estimated that about eighty per cent of all the gasoline sold in American filling stations was treated with tetra-ethyl lead.

When the word went around that Kettering and Midgley had spent $4,000,000 to stop a noise, oil refiners and automobile makers pricked up their ears, but few of them foresaw the impact of the discovery upon the whole transportation business. They saw demonstrators sprinkle a few drops of Midgley's fluid on their neckties and wave them before the intakes of knocking engines. When the very breath of the new fluid stilled the knocking, their eyes popped in amazement, but they were inclined to dismiss it as little more than a parlor trick. So Kettering, a master publicist, Midgley, his colleague T. A. Boyd, and others set out to explain just why the stopping of the noise produced more power from the fuel, and thus prepared the way for more efficient engines, more speed, heavier loads and faster acceleration.

Slowing down combustion

By this time they had more information about engine knocking. Under the aegis of General Motors, which had taken over the work, they had built larger windows in the sides of engine combustion chambers, and with fast motion-picture cameras had photographed the burning behavior of all manner of fuels. Slowing down these films to see what really went on inside the chamber, they found that the flame touched off by the spark traveled through the compressed, vaporized fuel like a forest fire, and that when an engine knocked, it was because the part of the fuel farthest from the spark plug "got excited" under pressure and exploded spontaneously before the flame reached it. If in pushing open a swinging door you give it a sharp blow with your fist instead of a firm, slow shove, you will get a rough idea of what knock does in an engine. It makes the engine fight itself, and this means wasted power and overheating. The addition of the lead mixture slowed down the spread of the flame, so that the fuel burned evenly and sent the piston down with a unified push that had everything behind it.



Knocking—the burning of the vaporized fuel, ignited by spark at left, is disturbed by premature explosion at right. (Courtesy General Motors Corp.)

Midgley's discovery was first offered to the public on February 1, 1923, at a Dayton, Ohio, service station. If a motorist wanted "anti-knock gasoline," the attendant turned a pet-cock and drops of tetra-ethyl lead flowed into the fuel as it was pumped into his tank. In many engines this additive deferred the knocking point under load, that is, many drivers could climb steeper hills without shifting. But the results were by no means uniform.

Improved engines were needed to match the possibilities of the new fuel mixture. A common complaint of drivers of the early twenties was the congestion at street crossings, where cars crawled painfully from gear to gear before they could develop normal speed. On the highways, long "funeral processions" accumulated behind slowpokes because engines could not furnish the quick spurt necessary to pass safely. And shifting on hills made for more congestion, snail-like travel, and ruined tempers. The whole future of motor travel depended on faster acceleration.

Engine designers had known for years how to make motors that would develop the necessary reserve power. Theoretically, they could do this by increasing the compression ratio of the cylinder—that is, by sending the piston in its upward stroke to a point nearer the top of the cylinder, thereby compressing the fuel mixture into a smaller volume. The ignited charge would then drive the piston downward with a more powerful shove. While it takes more power to supply the added compression, each additional expenditure of this sort yields a tremendous profit in downward thrust applied to the crankshaft.

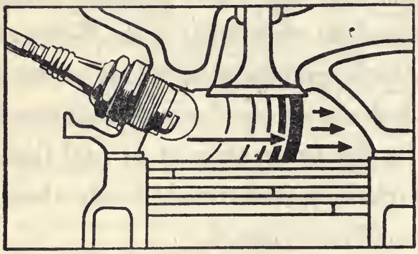
But engineers also knew that if you pushed the piston up beyond a certain point, the engine would knock, because no gasoline was being sold to match the more efficient engine. This was where Midgley came in with his new anti-knock fuel. Test motors were built in the General Motors Research Laboratories with high compression ratios to take advantage of the livelier gasoline. It was shown conclusively that these engines would deliver more power for the same amount of fuel than the average engine then in use, in which the piston traveled only about three-quarters of the distance to the top of the cylinder.

It was one thing to prove in a laboratory that better fuel would enable automobile manufacturers to build more efficient engines; to convince a manufacturer that he should pioneer in this field was quite another matter. Even General Motors, which had fathered the research project, was slow to change its engine designs. The company could hardly be criticized, for new fuels and new motors must travel hand in hand, and the car with a motor too good for average gasoline quickly gets a black eye.

Then came Chrysler, a new star in the Detroit firmament. His brilliant and tough-minded engineering team, Zeder, Breer and Skelton, looked toward the future and decided that drivers would demand more power, more speed and better pickup. There was only one way to build such a car without reverting to the huge arks of 1920, and that was by packing more power into an engine of the same size and using a fuel to match. There were bound to be a few difficulties of adjustment, but all signs pointed ahead, so the Chrysler Corporation stepped out and led the procession. They brought out the high-compression "Red Head" as an optional motor, and stamped on the cap of the gas tank "Use Ethyl Gas."

Enter the octane scale

More tests of new motors and fuels were made by the Ethyl Gasoline Corporation, which was formed by General Motors and Standard Oil of New Jersey to manufacture and market the anti-knock fluid. Since some fuels were much more susceptible than others to improvement by adding tetra-ethyl lead, there was great confusion, not only among drivers, but among the experts. It was imperative to formulate some sort of standard for measuring the anti-knock quality of gasolines. So Graham Edgar of the Ethyl Corporation worked out what he called the "octane scale." The least-knocking fuel then known was the rare iso-octane, or *2, 2, 4 trimethyl pentane,* as chemists call it, while the poorest performance was given by *normal heptane,* which knocks worse than kerosene. Edgar gave the former the perfect mark of 100, and pegged the latter at zero. So that if, for instance, you make a mixture composed of seventy per cent of the former and thirty per cent of the latter, the octane number will be seventy. This enabled chemists to compile racks of labeled bottles containing fuels of known octane numbers. A single-cylinder test engine, like the one which Midgley demonstrated at the meeting of chemists, was universally adopted as a means of grading the anti-knock value of any gasoline.



High-octane fuel burns more slowly and evenly, gives more power per gallon. (Courtesy General Motors Corp.)

As a result, the research men were able to select the appropriate fuel for the most advanced motors. They bought a new Chrysler, stepped up the compression ratio to a new high level, filled the tank with a high-octane gasoline, and arranged a contest at Dayton against a standard car of that year.

Carl Breer led a Chrysler delegation from Detroit and listened while they explained that the altered engine would give a twenty per cent better performance than the regular one.

"All right," said Breer, who had to be shown, "if that figure means anything, it must mean that if you add twenty per cent to the total load of this car, and race the two up a hill, they'll come out even."

Earl Bartholomew of Ethyl had not expected this challenge, but he was game. Breer, Jack Macauley of the Chrysler Corporation, and another solid citizen weighed in at a total of 660 pounds, and piled into the back seat of the test model. The two cars roared up the hill with their throttles jammed to the floorboards, reaching the top in a photo-finish.

Breer shook his head in amazement. "I never saw mathematics work like that before," he said.

It was, in fact, something of a miracle, because no matter what the octane rating of a gasoline may be, its performance may vary, not only in cars of different makes of any one year and in cars of the same make of different years, but also in new cars of the same make of the same year. For this reason the average driver has never been able to determine with any close degree of accuracy the precise octane rating of fuel which his car requires. But drivers have been sharply aware of generally improved performance, and that, not the mathematical coincidence, was what interested the motor makers.

Road performance like this was better proof than a page of figures, and soon after the Dayton test, 150 of these experimental cars were built and distributed among the gasoline companies to demonstrate the advantages of what was soon to be called "high-octane fuel." Ethyl traveling men drove the "mystery cars" to automobile salesrooms and took the dealers riding over hills.

Walter Chrysler was jubilant. "These cars have wings," he said. "This is the way to put the idea over. People will ride in them and tell their friends." K. T. Keller, then president of Dodge, and "Dutch" Bower, then chief engineer of Buick, decided that they had been missing a bet. They brought out engines with higher compression ratios, but to avoid penalizing the driver who didn't want to buy premium gas, they provided extra cylinder-head gaskets with each car. Any driver who found that his customary fuel was not adapted to the new motor could have the gaskets inserted to return the engine to its former status.

Soon the race between better fuel and engines built to utilize it swung into high gear, and drivers reaped the benefit of this twin development every time they stepped on the throttle. It has made it possible to get more and more power out of an engine without increasing its size and weight, or increasing the cost of the car.

The race between fuel and engine presented many complications. Some cars have appeared with appetites too finicky for most roadside gasoline, and some cars have lagged behind the procession. Engine-fuel combinations which were satisfactory in the flat Midwest caused intolerable knocking on New England hills. Octane ratings determined by bench tests were no sure guide to road performance. So a test road was selected in Uniontown, Pennsylvania, and there under the auspices of the Cooperative Fuel Research Committee, all makes of cars were jammed up a hill with wide-open throttles, and accurate records were made of speed, knock intensity, engine heat, and so on. These findings, applied to the standard laboratory test-engine, helped to bridge the gap between the chemist and the driver.

Then in the mid-thirties, tetra-ethyl lead, which had been sold only in premium fuel, began to be introduced in regular grades of gasoline, and by the time we entered the war, four out of every five gallons contained it. This made it possible for refineries to bring many gasolines of low octane number up to the standard required by modern cars. It also acted as a tremendous spur to petroleum chemists in their campaign to increase the octane rating of gasoline without the use of lead.

For the story of tetra-ethyl lead is only the prelude to the great drama of mightier fuels. Dr. Midgley and his colleagues were the pioneers. Their studies of fuels and engine behavior and their creation of the octane scale laid the foundation for greater advances. The compound which they put in gasoline has added billions of horsepower every year to the work output of American automobiles and airplanes, and is likely to continue to do so. But if when war came we had been forced to depend solely upon lead to step up aviation fuel, engine design would have been shackled and the whole Allied aviation program would have been hampered, probably with unpleasant results.

Dr. Midgley used to tell a fable about an altitude contest held by birds. The eagle soars far above the other birds, reaches his ceiling, and proclaims himself the champion. Just then a little bird who has been hiding beneath the eagle's wing jumps out, flies a few feet higher, and says, "You're wrong, I'm the champion." The little bird is tetra-ethyl lead, and Dr. Midgley's moral is: no matter how good gasoline gets to be, lead will make it a little better.

But the little bird can't fly very far above his carrier. When great quantities of high-octane aviation fuel were needed, the Army first tried to boost it to the required level by adding large amounts of the lead compound. This didn't work. The maximum amount of lead which can be added to automobile fuel is three cubic centimeters to the gallon. This limit was determined because of a possible health hazard in using more, but it is also the top limit for high effectiveness. Each additional drop beyond that limit gives a progressively lower return in octane value, as well as contributing to the deterioration of the motor. Some damage is done to spark plugs and valves by the lead in automobile fuel, but the benefits have greatly outweighed this shortcoming.

Four cc's of lead to the gallon are considered allowable in airplane motors, but the requirements of warplanes are so exacting that serious harm would be done by much higher concentrations of lead.

When war clouds gathered it became apparent that control of the air would go to the planes which flew faster, higher and farther and carried the greater bomb loads. Planes are built around engines, and engines are built around fuel. In the see-saw development, engines had gone as far as they could go, and were pressing against the limitations imposed by the properties of available fuels.

Builders of new fuels

In this atmosphere, the petroleum chemists came into their own. For many years they had been reconstructing the molecules of crude oil to produce gasolines of greater power, at the same time greatly increasing the gasoline obtainable from a barrel of crude. These hydrocarbon molecules naturally occur in an infinite variety of sizes and shapes, and the behavior of a fuel in a motor depends upon the exact structure of its molecules as selected by the refining process. Far from being a standard, uniform substance, petroleum is a little universe. We may think of it as a column ranging from a thick asphaltic sludge at the bottom, composed of great molecules too big for gasoline, to volatile gases at the top, whose molecules are too small. From this vast range of molecular building blocks chemists can produce an evening gown, an automobile tire, a plastic ashtray, TNT, insecticides, potable alcohol and a thousand other products.

"Practical" oil men once looked upon the research worker as a long-haired visionary, but the great strides made by petroleum chemists in the last decade constitute one of the most remarkable achievements of industrial science. Many methods have been found for remodeling hydrocarbon molecules, and plants based upon these methods have sprouted so fast that some of them have become obsolete in a few years.

To the chemist, the methods are vastly different, but they can all be generally described as ways of reshuffling the atoms of carbon and hydrogen. It was found, for instance, that when the carbon atoms in a molecule of motor fuel are arranged in a straight line, like a file of soldiers, the fuel will knock badly. Bunch the atoms together and perch them on one another's shoulders like a troupe of acrobats, and the knocking stops and more power is obtained from the fuel. And this "bunching" cannot be haphazard. The exact position of each atom is important in the final result. Research men have diagramed and tested hundreds of these patterns, and there are literally millions of combinations waiting to be catalogued.

In the early days of the automobile, the refiner simply distilled the crude oil, and the more volatile part which vaporized and trickled down through the cooling coils was gasoline of very poor grade, according to present standards. Only a narrow band of the petroleum column was converted into gasoline by this method, and much of the residual crude became a drug on the market.

Then refiners found that by means of increased heat and pressure, they could literally "crack" many of the larger, heavy molecules into building blocks of gasoline size. There is a legend that this method was first discovered accidentally in 1861, when a stillman in Newark, N. J., left his still for four hours, when he should have returned in one hour to remove the residue after the normal amount of gasoline had vaporized and run off. The temperature became so high during his absence, according to the story, that some of the residue was cracked into additional gasoline. William Burton introduced the first successful "thermal cracking" process, as it is called, in 1913. Then in 1919, twenty-one refiners gathered behind a high board fence in Independence, Kansas, to see an oil chemist named Carbon Petroleum Dubbs demonstrate the cracking process which his father had developed and he had improved upon. This new thermal process for converting residual oil into gasoline became immensely successful.

Controlled by Universal Oil Products, it was soon used under license by scores of American refiners.

Thermally cracked gasoline played an important part in raising the octane rating of automobile fuel and thus enabling Detroit to develop more efficient engines, but it is not suitable as a base for 100-octane aviation gasoline. For this purpose, natural gasoline of an especially high grade was used, but the supply was limited.

Cracking with catalysts

Then came the "cat crackers." By using a catalyst (a substance which produces a chemical change without itself undergoing change in the process) refiners achieved new triumphs in the conversion of low-grade oils into high-octane gasoline. While thermal cracking changes the big molecules with terrific heat and pressure, the cat crackers take them apart and rearrange them more gently, swiftly and efficiently, and give the refiners more exact control of the products. The first large-scale catalytic cracking method was the invention of a Frenchman named Eugene Houdry. He arrived in the United States in 1930 with a crate of apparatus and some clay pellets made of fuller's earth and shaped something like elbow macaroni. The clay pellets were used as catalysts in his miniature refinery—when vaporized oil was passed through them, its molecular structure was altered, and a fuel of high anti-knock value came dripping out. He had made several gallons of this fuel and tested it in his automobile. Clay pellets were no novelty to petroleum chemists, who had used them for years in various shapes and sizes. The fact that they fouled and became useless in a few hours limited their effectiveness in an industry geared to continuous operation. But Houdry had found a way to cleanse them quickly, and had solved other difficulties that stood in the way of large-scale production. He joined forces with the Sun Oil Company, which was receptive to any process by which high-octane automobile fuel could be produced without adding lead. Many millions were spent on new plants built according to Houdry's specifications. Beds of the pellet catalysts were held in racks so that they could be alternately cleansed of carbon as the vapor stream was diverted from one to another. The gasoline from these plants had such a high octane rating that it was used to doctor poor automobile fuels. A number of refining firms adopted the process, and the Houdry plants are now turning out high-octane base stock for aviation fuel.

Greater amounts of this base stock are produced by newer catalytic cracking methods which have gone into production since the war began. In the Thermofor process, controlled by Socony-Vacuum, catalysts in the form of beads do their work by moving slowly down through the hot oil vapors. The first really continuous process, which was developed by Standard Oil of New Jersey, is the "fluid cat cracker." The secret catalyst is ground into a fine white powder which looks like cake flour, and is shot into the refining stream at high velocity. As a powder, the catalyst exposes far more surface to the oil vapors than do the pellet or bead types, and it does its work in a few seconds. Treated as a liquid, it travels with the oil stream, and after it has served its purpose, it is automatically reclaimed and cleansed, and is ready for another cycle of work.

A large number of the bead and fluid catalytic cracking plants—towering, grotesque masses of columns, pipes and tanks, without walls or roofs—have been built by the government since Pearl Harbor. They are among America's mightiest weapons of supply. By cracking the big molecules of gas oil, which is similar to household furnace oil, they produce basic ingredients for TNT and synthetic rubber as well as a base stock for making 100-octane gasoline. They also produce special high-octane compounds called alkylates, one of a number of varieties of "blending agents" used to bring gasoline up to the highly developed taste of the latest airplane engines. For aviation fuel is made by complicated recipes, and each added ingredient increases the octane rating. In meeting the war program, refiners have often faced the dilemma of a chain coffee drinker who at one moment hasn't enough sugar for his coffee, and later hasn't enough coffee for his sugar. Step by step the program has been brought into balance, and in 1944 the powerful aviation fuel was being produced at the rate of six billion gallons a year, which is about one-quarter of the total motor-fuel consumption in the United States before the war.

Aviation gasoline is still loosely described as "100-octane," but the fuel now used in our warplanes is, in terms of motor performance, far above the "perfect 100" mark of yesterday. One hears talk of "130-octane fuel" and better, but these are only estimates. In grading flying fuel the octane scale is now obsolete, and completely new measuring methods have been devised as a result of discoveries concerning fuel performance in fast planes.

One of the newest methods of bettering the performance of an airplane fuel and thus getting a momentary burst of extra power from the engine is by injecting plain, ordinary water. By a method developed by the Pratt and Whitney Aircraft Company, the pilot who is in a tight spot turns a control and sends a tiny jet of water into the fuel mixture. This cools the motor and temporarily increases the octane rating of the fuel mixture. The result is a burst of speed which has saved many lives.

Super fuels to come

Chemists have discovered a number of molecular keys which are unlocking still more hidden reserves of power in petroleum. Many of these developments are secret. One new fuel, called triptane, has a higher anti-knock value than any other hydrocarbon compound ever produced, according to widely published reports. Only a few years ago, triptane was produced in small laboratory quantities at a cost of $3,000 a gallon. Now, due to the work of Dr. Vladimir Ipatieff, Russian-born research director of Universal Oil Products, and Dr.

Vladimir Haensel of the same firm, it is being made commercially to sell for less than $1 a gallon. There is no motor in existence which can utilize this mighty fuel by itself, but when used in a blend it will greatly enhance the performance of present-day aircraft motors, and it will doubtless help pave the way for the development of future engines of even greater power and efficiency.

Supergasolines developed for war use will inevitably improve the performance of postwar automobiles, and experts are predicting gasoline in the neighborhood of 100 octane for the cars of the future, with engines designed to use it.

Tests conducted in Detroit a few years ago gave some idea of what this would mean to the automobile driver. Engineers took a standard new car, increased the engine compression, changed the axle ratio, and filled the tank with ninety-five-octane fuel. They spurted up steep pitches that stalled the regular model, got a higher speed, and used twenty-five per cent less gasoline per mile. Another test car using 100-octane fuel used forty per cent less gasoline while traveling at forty miles an hour. When they tested a rare, numberless fuel somewhere above the known octane scale, miles per gallon at the same speed were increased by sixty-five per cent, and acceleration was also improved. That is, if your car is giving you eighteen miles to a gallon, this superfuel would boost the mileage to almost thirty, with somewhat better hill performance and pickup thrown in for good measure.

Such tests should be taken only as guide-posts to the future of automobile travel. No one can predict what tomorrow's car will be like without also considering various mechanical improvements which are under way, and such possibilities as the increased use of light metals. Some engineers, after weighing all these factors, suggest that a few years after the war the average automobile may yield twice the mileage per gallon we were getting when Pearl Harbor interrupted progress in non-military transportation. The price of aviation gasoline in mid-1944 was six cents a gallon higher than the price of automobile fuel, but even if the differential should remain the same, the net cost of automobile transportation would be reduced.

Of far greater importance is the saving in our dwindling petroleum reserves which may be effected in two ways: by getting more fuel out of the crude, and by getting more mileage out of the fuel. For more than two decades there has been steady progress in the former economy: cracking methods have reduced by more than fifty per cent the amount of petroleum needed to yield a gallon of gasoline. With the newer refining methods, more progress is inevitable in this direction, and oil chemists optimistically predict that nearly all the crude can be converted into motor fuel if such a course seems desirable.

On the other hand, the constantly increased power in automobile fuel has been spent mostly on higher speeds, faster acceleration and smoother riding. There was great need for improvement along these lines, but now that we are about to become an oil-importing country, it is only a matter of time before American drivers will choose—or will be forced to accept—more miles per gallon instead of still greater speed and pickup.

Before our petroleum wells run dry, other prime movers may supplant the gasoline-burning internal combustion engine. In the meantime, the boundaries of petroleum research are practically unlimited. Technical men have stated that in every gallon of gasoline there is a theoretical 250 miles or more of travel. Their accomplishments are impressive, but they have only made a start in tapping this tremendous reservoir of energy.

CHAPTER SIX

THE RISE OF DIESEL POWER

THE MOST EFFICIENT and economical prime mover ever invented is the Diesel engine. It converts about fifty per cent more of the heat units of its fuel into power than does the gasoline engine, and is three times as efficient as most steam locomotives. It burns a cheap oil fuel which costs about half as much as gasoline, and it has no ignition system to get out of order.

Despite a common impression that this paragon of motors is something new, it broke all efficiency records nearly fifty years ago, and has been running steadily ever since. The first working Diesel in the United States turned its flywheel in St. Louis in 1898, a year after its inventor translated his blueprints into a practical motor. Yet it was neglected for more than three decades, and it took the depression, with its emphasis on operating economy, to start the long-deferred Diesel boom in the United States.

Today the Diesel is everywhere, and enthusiasts hail it as the hope of the future. In sizes all the way from five to 8,000 horsepower, it propels freighters, naval vessels, tanks, busses, bulldozers and trucks. It drives the generators of municipal light plants and furnishes cheap light and power for hotels, apartment houses, hospitals, department stores and refrigeration plants. It turns the wheels of factories, and has even driven passenger cars and airplanes with its customary economy. In every field, stationary or moving, in which power is used, the Diesel is now either an active competitor or is potentially imminent.

While the depression turned the attention of Americans to the Diesel's merits, the war has spurred production of the engine to figures once undreamed of. Back in 1939 the manufacturers celebrated a boom year. They had turned out a total of 2,144,000 Diesel horsepower, which represented an increase of about 500 per cent in a decade. Last year this triumph was dwarfed as their output reached an estimated 25,000,000 horsepower. Most of these motors were for the Navy, the Army, the Maritime Commission and Lend-Lease, and peace will bring an epidemic of order cancellations, yet it is expected that events since Pearl Harbor will bring about increasingly wide use of the oil-burning motor. New factors introduced by the war are likely to hasten the already growing trend. Major improvements, many of them secret, have been made in the motor in the last four years. Even better performance can be expected after the war, as well as lighter, smaller engines of the same horsepower. Another factor is the impending petroleum shortage, for the war has speeded the exhaustion of our irreplaceable oil capital. Before many years have passed, fuel economy, long ignored in the United States, will become a highly important virtue in an engine, and in this field the Diesel stands in a class by itself.

Behind the motor which bears his name looms the almost legendary figure of Rudolph Diesel, one of the most brilliant mechanical geniuses of the nineteenth century. The engine was his life work, and its superior efficiency is the direct and planned result of his long, arduous years of almost consecrated labor. It all began when Diesel, then a boy in his teens, sat in a classroom of the Munich Technical Institute, listened to a lecture, and saw a small gadget that looked like a popgun.

Diesel was a Paris-born Bavarian, offspring of a long line of German artisans, whose stern father began drilling him in mechanical principles as soon as he could talk. A misfit among his Parisian contemporaries, he spent his time going to technical museums and absorbing wisdom from his elders. When the Franco-German War broke out in 1870, the family fled to London. Almost destitute, they sent the boy to a cousin in Germany, a martinet professor of mathematics. Rudolph dashed meteorically through trade school and industrial school, then won a scholarship at Munich. When he graduated at the age of twenty, he had broken every academic record in the Institute, and the astounded faculty met him in a body and shook hands with him.

The lecture which inspired him was given by his favorite teacher, Dr. Carl Linde, who was famous for his pioneer work in artificial refrigeration. He spoke of the wastefulness of the steam engine. He pointed out that when you burned fuel in a furnace, produced steam, and conducted the steam through pipes to develop power in the cylinder of an engine, energy was lost all along the line, and that most steam engines then in use wasted ninety per cent of the energy in the coal. Then he told of the Carnot cycle, a method, existing only in theory, by which an engine could function most economically.

Diesel listened with growing excitement, and scribbled furiously in a notebook which has been preserved. He wrote:

> *"Mechanical theory teaches us that only a part of the heat in the fuel can now be utilized . . . Doesn't it follow from this that the utilization of steam, or any kind of go-between, is false in principle? The possibility suggests itself of putting the energy to work directly, without a mediator. But how can this actually be done? That is the problem."*

Hint from a cigar-lighter

The popgun-like gadget which Diesel saw at Munich was a cigar lighter used in the Far East. It is sometimes called a "Polynesian fire syringe." The air in the cylinder, heated by the compression of a plunger, ignites a bit of combustible material, providing a flame. This gave Diesel a hint as to how he could "put energy to work directly." From that time on, the problem he set for himself in his notebook was always with him, but fifteen years were to pass before he found an answer that suited him.

When Diesel left school, Professor Linde, who manufactured ice machines, made him his Paris agent. Within a year he was a director of the company. After long days at the plant, he went home to work with slide rule and compass, formulating and scrapping plan after plan for the new efficient engine of his dream.

It was uphill work. When he was thirty, he said he felt like an old man, and rebuked himself for having accomplished so little. He had turned out other inventions, but they had come to little. He had made a machine for freezing ice in cubes, but a cold winter brought a glut of natural ice and it failed to catch on.

Later he was transferred to Linde's Berlin office. The pile of blueprints and pages of figures kept mounting on his desk, and the time came one night when he decided that he had his teeth in something. He didn't leap up and yell "Eureka!" He was a scientist, and things had to be proved, but this was his plan:

The popgun gadget had reminded him that the more you compress air, the hotter it becomes. Put your hand on the rubber tube of a bicycle pump in action and you get the idea. Now why not build an engine in which the piston pulls in nothing but pure air in its loading stroke, and then drives back toward the cylinder head, compressing the air to about one-sixteenth of its former volume. Then, he computed, the air would be about 1,000 degrees Fahrenheit, about the temperature of red-hot iron, and much hotter than the combustion point of oil.

At that point a drop of oil would be injected into the cylinder. The hot air would ignite the oil, and its combustion would drive the cylinder down. Then he compared his theoretical motor with the gasoline engine. With his plan there would be no ignition system, since his engine would do its own igniting in the cylinder.

Confident that at last he had hit upon the solution, Diesel redoubled his energies. Many men would have gone into the machine shop at that point and proceeded by the trial and error method, but that was not

Diesel's way. Everything about that engine, down to the last bolt, had to be figured out and put down on paper.

At length he took a manuscript to the printer, and the Diesel family went through an anxious period of waiting. He had already taken out patents. In January, 1893, the work was published. "Theory and Construction of a Rational Heat Motor" is a slender pamphlet. It is a maze of efficiency curves, diagrams and mathematical formulas incomprehensible to the layman, but it belongs with that small shelf of books which have changed the world.

Diesel knew that not more than a score of men on earth would grasp its significance, and was prepared for coldness and ridicule. He got both. Scoffers called it a "paper engine," for it existed only in a book. There was a whispering campaign that he had appropriated ideas not his own, and certain men who were afraid that the motor might injure their businesses spread word that it couldn't possibly work. But there were a few technical men who accepted Diesel's conclusions, and their opinion carried weight. Krupp, the big industrialist, agreed to finance the invention. Six months after the pamphlet appeared, Diesel was building his engine in the Augsburg Machine Factory.

Shout of triumph

In August, 1893, the motor was finished and ready for a test. The inventor stood in the machine shop, anxiously watching an upright, pump-like contrivance with a slowly revolving flywheel. The workmen looked on with friendly skepticism. No engine like this had ever been seen before. The outlandish thing took outside power to push the piston up and down. Diesel waited impatiently. At last the moment had come. Eyes blazing with excitement, face fevered from weeks of labor, he pulled a lever and the vaporized fuel spurted into the red-hot air.

There was a blast like a cannon shot, and chunks of metal bombarded the room. Barely missed by death, Diesel leaped to his feet with a shout of triumph.

"That's what I wanted to know," he said. "It proves I'm on the right track!"

Quickly he drew up plans for a second engine, in which the cylinder was water-cooled and the fuel was injected by means of compressed air. This engine developed power enough to turn over the flywheel, but it ran for only one minute. A third model came nearer the mark, but it was not until the fourth engine had been turned out, almost four years after he had set to work in the Augsburg shop, that his concept was practically demonstrated.

The world's most famous engineers flocked to Augsburg to see the twenty-horsepower "Dieselmotor," as Mrs. Diesel had christened it. They made careful tests, and the results amazed them. Even the best steam engines of the day did not convert into power more than fifteen per cent of the heat value of the fuel used, but here was a new engine which at once showed an efficiency of more than thirty per cent.

Among the pilgrims who went to Augsburg was Col. D. C. Meier, New York engineer. Adolphus Busch of the St. Louis brewing firm was in Paris, on the point of sailing for home. When he heard that Meier was in Augsburg, he cancelled his passage and asked Meier to meet him in Paris. Meier told him that what he had heard about the new engine was true and Busch jumped on the next train, wiring Diesel to meet him half way. They met at Cologne, and came to a rapid-fire agreement giving Busch the sole right to manufacture the new engine in the United States. Busch took his boat, and within a year a six-horsepower, two-cylinder Diesel was set to work in St. Louis.

In 1912, Dr. Diesel, then at the crest of his triumph, was feted in the United States, and made a prophetic speech before the American Society of Mechanical Engineers in New York.

"Nowhere in the world," he said, "are the possibilities of this prime mover so great as in the United States." Yet it might be years before this development took place, he explained, for American industrialists were less interested in long-term efficiency than in huge profits. With fuel cheap and plentiful, they wanted low-price engines, regardless of operating cost, and the Diesel, he said, was a comparatively expensive engine and always would be. Europe was far ahead of America in the use of the Diesel, he said, because fuel costs were higher abroad, and industrial competition was keener. But he foresaw a time when America would be forced to turn to more economical operation. Then his engine would come into its own. For Dr. Diesel regarded his engine, not as an isolated piece of machinery, but as an instrument for human development.

Mystery story

Within a year Dr. Diesel mysteriously disappeared. He was crossing the Channel at night to confer with the English Admiralty about the use of his motor, which had been adopted in submarines. The boat arrived at Harwich without him. Because war broke out soon afterward, there were rumors of conspiracy and foul play, and the mystery has taken a place in popular lore along with that of the derelict *Marie Celeste.* Rumors that Dr. Diesel has been seen are heard now and then, and mystery-lovers like to believe that he is now living in seclusion at the age of eighty-seven. But the plain truth, judging by a recent biography written by his son Eugen, is that he had been speculating unwisely to secure funds for the further promotion of his engine, and had chosen suicide instead of the disgrace of bankruptcy. So Diesel the man was soon lost in the cobwebbed files of obscurity, and Diesel the engine went on to fulfill its mission.

One of the chief missions of his invention, Dr. Diesel had said, was to place the small power user on an equal footing with the big industrialist. The coal supply was already limited in Europe, and the engine was rapidly adopted by small factories which had not been able to produce coal-steam power as economically as the big plants. Its use spread to the United States—slowly, because fuels have always been cheaper here—and it was adapted for marine use. The Diesel became standard for the submarine because its fuel took up less room than an equivalent amount of gasoline and was less of a fire risk.

One reason why the Diesel is more efficient than the gasoline engine lies in the difference in compression ratios. The Diesel ratio is sixteen to one, while the gasoline-engine ratio is only six to one, or seven to one in some of the newer engines designed to use high-octane fuel. That is, the Diesel piston travels fifteen-sixteenths of the distance to the cylinder head before combustion drives it downward, and the gasoline engine piston travels only five-sixths of the distance. If we think of the contents of the cylinder during the compression stroke (in the Diesel engine, pure air; in the gasoline engine, a mixture of air and gasoline) as a steel spring, it is obvious that the greater the compression, the greater the power of the spring's recoil when it is released. Like most analogies, this does not give the complete story, for in the motor, the work required for each added bit of compression yields a four-fold dividend in power. For other and more complicated reasons, the Diesel wastes less heat through the cooling jacket than the gasoline engine, applying a higher percentage of the heat generated in combustion to the business of creating horsepower.

Today, top Diesel efficiency is about thirty-seven per cent, compared with perhaps twenty-five per cent for the gasoline engine and twenty-nine per cent for some of the newest steam-turbine units, while many steam locomotives still in service do no better than ten per cent. After a glance at these figures, the non-technical reader is probably wondering why steam and gasoline engines have not gone the way of the dodo. The answer is that operating efficiency is only one factor to be considered in the purchase of a motor, or any other machine or gadget. First cost is of equal importance, and this factor fights its battle with efficiency in every industrial drafting room. The older and more stable a civilization, the greater is the tendency to pay a higher initial price for a machine and reap the slowly accumulating benefits of operating savings. In the comparatively static pre-1914 European economy, with its limited opportunities for speculative enterprise, the man who ran a small factory usually expected to run it for life and pass it on to his son, and he bought his equipment accordingly. This attitude would have been considered a confession of defeat in the expanding Western Hemisphere, where entrepreneurs sought quick fortunes and their sons departed for greener fields.

A variety of other factors retarded Diesel development, and one of the most important of these was the bulk and weight of the engine. Speaking of motors in terms of horseflesh, there is the draft horse at one extreme and the race horse at the other. For a long time the heavy Diesel was limited to draft-horse uses. But between the two extremes there is a third category—a tough, wiry animal good for pulling intermediate loads under all sorts of conditions. He is the indispensable mule. He is the truck, the tractor, the excavating shovel, the cement-mixer, the highway bulldozer and the passenger bus. Among the spectacular accomplishments of recent years has been the breeding of the Diesel mule.

Hoosier engine builder

Scores of firms and individuals have played a part in this development. Diesel's patents have been in the public domain for many years, and by constant improvement, the motor has been adapted to uses that the inventor never thought of. One of the ablest of the adapters is Clessie Cummins, engine builder of Columbus, Indiana, pioneer of the automotive Diesel. Cummins, who began life as a daredevil woodshed inventor, is as American as the scholarly, precise Dr. Diesel was German. He saw little of schools, and learned about engines from hanging around the garages and workshops of the early 1900's. His boy-hood was filled with madcap escapades with home-made gas-buggies, motorcycles and power boats, and he remained alive by sheer luck. He was a Tom Sawyer with a monkey wrench. World War I found him driving the car of William G. Irwin, prominent industrialist and leading citizen of Columbus. When the family went away for vacation he passed the time making hubs for government wagons, and they returned to find that the family garage was a factory running in three eight-hour shifts. Irwin responded by setting his driver up in business, and Cummins began to experiment with Diesel engines. After years of work, he brought out a satisfactory light-weight Diesel marine engine suitable for yachts, but with the stock-market crash of 1929, yachts went out of style.

On a gray December morning that year, Cummins went to his idle factory, picked up a trade magazine containing a survey of Diesel developments, and found that his name was not mentioned. He was annoyed. He went to a used-car lot, bought an aged Packard limousine and trundled it to his shop. For three weeks he and his brother labored day and night, and on Christmas morning he drove the car to Irwin's house and took him for a ride. After a few miles he stopped the car and opened the hood. His partner stared in amazement. The engine was a four-cylinder marine Diesel made in their plant.

With that battered old hulk Clessie Cummins launched a new epoch in American highway transportation. He did not try to lock horns with Detroit in making passenger cars. His goal was a highway Diesel that would compete with the gasoline engine in trucks. Meanwhile, newspaper headlines wouldn't do any harm, and Cummins was ready with the steam calliope and the trapeze acts.

The annual automobile show was about to open in New York, and Cummins announced that he was coming to the show in his Diesel. Reporters gathered at the starting post in Indianapolis, officials sealed his fuel tank, and he was off in the untested car on an 800-mile gambol over the winter roads. In spite of a number of mishaps, he arrived on schedule. The trip became a sensation, and people talked about Diesels who had never heard the word before. Cummins had averaged thirty-five miles to a gallon of oil, and his fuel cost for the trip was $1.38. More stunts followed. He mounted the same engine in a racing body and did 100 miles an hour on Daytona Beach, Florida, and on the Indianapolis Speedway he drove it 500 miles without stopping or refueling. The climax came when he drove a Diesel-powered Auburn coupé from New York to Los Angeles, in an economy test, at a fuel cost of $7.68. The cost of gasoline would have been between $35 and $40. The entire world heard about this trip, and Cummins toured Europe, demonstrating his car on race tracks.

Flirting with death

Many people who heard of these triumphs assumed that a Diesel automobile was just around the corner, but Cummins explained that the purpose of the tests was simply to show what a Diesel would do on wheels, and that the motor he was designing as a result of the trials was too expensive and longlived to install in low-priced, mass-produced passenger cars. He was setting his cap for operators of heavy-duty commercial vehicles which ran up high annual mileages, for they were in the best position to profit by the engine's fuel economy. Next came a series of truck tests which added gray to his hair. There was a transcontinental run in which his brakes gave out on a long hill with a railway crossing at the bottom where a slow freight was passing. He missed the caboose by a few feet, and lived to report a fuel cost of $11.22. He took the truck to the Indianapolis Speedway and put a cot in the rear, and he and a relief driver circled the track fourteen days and nights to establish a non-stop record of 14,600 miles. They refueled only once during the ordeal from an oil truck which traveled alongside. This greatly impressed the big trucking firms, for time spent in filling stations adds substantially to their annual operating costs.

These tests were no mere publicity stunts. Back in the plant, Cummins tore down the engine and photographed every part, acquiring new data for its improvement. Soon trucks driven by Cummins' engines began to appear on Western roads. The truck manufacturing firms hesitated to adopt the motors, but Cummins persuaded truckers to turn in their gasoline engines and install his Diesels. California fleet owners bought heavily, and reported a net saving of eighteen per cent over gasoline truck operation. They were particularly enthusiastic about the Diesel's performance on hills.

Cummins sold his first truck engines with fear and trembling, lest an inexperienced driver make a mistake and his engine get the blame. Roadside garage men knew nothing about Diesels, and whenever there was engine trouble, the trucking firm wired the maker. In the summer of 1933, a truck broke down in the desert with a perishable cargo of meat. Cummins knew that the driver had clogged the engine with poor fuel oil, but he paid for the meat, and the gesture brought rich dividends. Cummins soon proved his point. His production curve soared, and since then he has built numerous additions to his plant. He still ranks as a small manufacturer. There are more than thirty well-known makers of Diesel engines in the United States, and he is not among the leaders in volume production. Other makers of light-weight Diesels have profited by his enterprise. Someone had to risk his shirt to prove the merits of the highway Diesel, and the resourceful, effervescent Hoosier had what was needed.

The tractor is another machine which has gone Diesel. It happened in a roundabout way. In the twenties the Caterpillar Company, biggest American makers of gasoline-driven tractors, found its export market menaced by the competition of foreign-made Diesel machines. So in 1931 Caterpillar's engineers developed an improved tractor Diesel. American customers demanded them. The oil-burning "cats" became famous all the way from jungle to ice-field, and now they are serving with the troops. Other American manufacturers, notably Hercules and

International Harvester, also brought out high-speed, light-weight Diesels in the early thirties to compete with the gasoline engine in various jobs.

Diesel streamlined trains

One of the most spectacular power innovations in recent years was the advent of the Diesel-electric streamlined trains. This field was opened up by the General Motors Corporation, which is now the largest manufacturer of the engine, turning out everything from truck motors to big stationary power plants. In 1930, General Motors took over the Winton Engine Company of Cleveland, which had been making Diesels for years, and with their superior financial and engineering resources, began to sweat down the old draft horse to mule proportions.

While Cummins stuck to Rudolph Diesel's original four-stroke-cycle principle, in which the piston travels the length of the cylinder four times for each power stroke, Winton and General Motors developed a faster, lighter, two-stroke-cycle motor—a type by no means new—which delivers two working blows for each blow of the four-stroke-cycle motor. This was done by eliminating one of the piston's round-trip journeys, which does nothing but drive the burnt gases from the cylinder. When the piston goes down on its working stroke a "door" opens near the bottom of the cylinder and fresh air blows through, driving out the gases so that the next compression stroke can start immediately. "Traffic" is expedited as in a streetcar which has an entrance at one end and an exit at the other. It is somewhat more complicated, but will deliver almost as much power as the four-stroke-cycle motor with half the number of cylinders. Further weight-saving was gained by skeletonizing the cylinder walls—substituting two thin steel walls with braces between them for the old, heavy, solid wall.

When two of these new General Motors Diesels were shown at the

Chicago World's Fair in 1933 the railroads showed sudden interest. Here was an internal-combustion engine small enough to fit the space requirements of a locomotive and powerful enough to compete with steam. Chicago, Burlington and Quincy and Union Pacific led the rush. In the fall of 1934, the U. P.'s streamlined train M-10,001 arrived in New York with a transcontinental speed record and the news that it had spent only $83 on fuel for the 3,260-mile dash. There are now more than sixty Diesel-electric streamliners in service. They are remarkable for swift, jerkless acceleration, and they are easier on roadbeds than the steam locomotive. Diesel freight engines are also making big inroads in steam. They cost twice as much to buy, but half as much to operate, and make fewer trips to the repair shop. The Santa Fe line reports that one new freight Diesel replaces nine old steam locomotives.

The Diesel invaded the passenger bus field in 1937 when Public Service Coordinated Transport of Newark, N. J., put twenty-seven of the oil-burning busses in service on a city-suburban line. Results were so good that Public Service added more than 300 to its fleet, and a few years later Diesel busses were running in New York, Chicago, Boston and other cities. Greyhound Lines became interested, and had 3,000 Diesels in service when the war put a stop to civilian orders. Comparisons show that these busses are getting about fifty per cent more miles to the gallon than similar gasoline-burning vehicles. Diesel makers are preparing for a big postwar expansion in this field.

The "pancake" Diesel

General Motors is also responsible for a revolutionary new lightweight Diesel which has been manufactured in large numbers to drive submarine chasers. It originated in a rough pencil drawing which the versatile Charles F. Kettering showed to Rear Admiral H. G. Bowen, director of the U. S. Naval Research Laboratory, in the summer of

1937. It was something new in Diesels. The sketch called for sixteen horizontal cylinders to be grouped around a vertical crankshaft in banks of four cylinders each. Admiral Bowen was so impressed that he got the government to put up $250,000 for the work of translating Kettering's scrap of paper into an engine.

Production of the "pancake Diesel," so-called because engineers saw a resemblance to a stack of cakes, began in 1942. This engine is only one-third the size of the best previous Diesels of the same horsepower, and it is said to be the lightest-weight ocean-duty Diesel in the world. On sub-chasers, the saving in space makes room for more fuel and increases range, while the saving in weight allows heavier armament or other additional cargo. Since both these savings are equally important in locomotives and trucks, the "pancake" may be adapted for land use after the war. General Motors is definitely preparing for a great postwar Diesel expansion, and this motor may be one of its leaders.

This is only one evidence of the recent Dieselization of the U. S. Navy. At the end of World War I the only Navy Diesels were on submarines. Now many millions of horsepower are in use, on craft ranging from the 45,000-ton *Iowa* to the smallest tug.

Cheaper power and light

Meanwhile, Rudolph Diesel's prediction that his engine would serve as a "yardstick" of stationary power has come true in the utility field, and there are apartment houses, hotels and communities all over the country which own and operate their own Diesel-electric plants. In New York City more than a hundred big electricity consumers, living in the shadow of one of the world's greatest utility corporations, make substantial savings in this manner. Among the establishments which use Diesels to produce either a part or all of their power are the Public Library, Columbia University, the Hotel New Yorker, the American

Telephone and Telegraph Company, Mt. Sinai Hospital, Macy's, Altman's and the Namm Store of Brooklyn.

The Namm Store has become Exhibit A for makers of the engine. Mayor LaGuardia called its private plant a "footstick" when he dedicated it in 1936, and it has more than lived up to expectations. Its Diesel-made electricity runs the lights and the elevators, the jacket-water from the engines helps to heat the building, water passed through the exhaust is heated for dishwashing and cleaning, and the surplus kilowatts furnish light for small neighboring shops. The complete cost of the plant was $200,000, and the store has reported a saving of $27,000 a year.

Because of proved savings like these, Diesel manufacturers are able to offer easy terms to other establishments which wish to divorce themselves from utility networks. The success of these plants depends on a number of things, among them the local utility rates and the competence of the engineer who runs them, for Diesel plants do not run themselves. Many plants have paid for themselves in six years, and some Diesel firms have installed the equipment for a nominal down-payment, the balance to be paid out of savings in the electricity bill.

Utility corporations do not twiddle their thumbs while competitors go after their markets, and some of them have spent large sums buying up private Diesel plants for their nuisance value and junking the engines. Such transactions by the Consolidated Edison Company of New York brought about an inquiry by the State Public Service Commission, which found that Edison had been buying Diesel plants "at prices greatly in excess of the reasonable value thereof," and that they had originally charged these acquisitions to operating expenses. The inducements offered to Diesel-users to return to the fold were held by the Commission to be illegal, and the practice was stopped.

Efforts of utility corporations to suppress the oil-burning rival have led to some amusing results. When the Diesel menace first raised its head, corporations lured back many customers with attractive power contracts, but neglected to buy the engines. So the returning prodigals sold their Diesels to other establishments who promptly left the fold, and the light company's efforts simply served to spread the Diesel doctrine. When a midwestern utility firm regained the account of a small factory which had been using its own power, it bought the engine but neglected to pick it up. After the favorable power contract had expired, the factory repurchased the engine at its junk value through a third person and put it to work again. Since Diesel engines refuse to wear out, it soon became clear that it took a sledge-hammer to put them out of business.

The success of certain municipal light plants with Diesel power is a story by itself, and communities of low-cost dwellings are suggested as a field for private Diesel-electric installations. There are Diesel-driven rural cooperative light-and-power systems, among them a 4,000-farm plant in the Shenandoah Valley. Individual large-scale farmers are using small Diesel-electric units to advantage, especially when they have water to pump and poultry houses to heat. But in spite of the Diesel's economy when it is given enough work to do, it is too expensive for the light, irregular loads used by single houses and small farms. There the utility company does the job more cheaply, and probably always will. Nor does it follow that the big utility firms can profitably supplant their steam turbines with tandem rows of Diesel engines, for the turbine is efficient and coal is cheap. For the present, at least, the Diesel is most economical when it carries loads which are neither too light nor too heavy.

Ever since Clessie Cummins made headlines with his experimental automobiles, motorists have been speculating about an economical Diesel passenger car. Mr. Cummins still fondly cherishes his Diesel-powered Auburn, and likes to take visitors to ride in it. Idling at the curb, and at low speeds, the heavy motor has a formidable clatter, but at seventy miles an hour, this noise is not noticeable. Drivers accustomed to the soft purring of a gasoline engine would probably object to the clatter, but of more importance is the fact that the necessary weight which makes the engine noisier also helps to make it more expensive. Cummins' truck motors are guaranteed for 100,000 miles. Such longevity would be superfluous in a passenger car, and there appears to be no way to make an inexpensive, short-lived Diesel motor. Before the advent of wartime gasoline rationing, American drivers showed little interest in fuel economy, and comparatively few bought expensive cars which would yield slow dividends over a long period. If the major firms had placed Diesels in light cars, their price would have been lifted beyond the reach of the average driver, and the whole carefully planned automobile distribution structure would have been demolished.

Any worthwhile consideration of a popular Diesel automobile would require knowledge of secret wartime improvements in the engine, and speculation on such matters as the probable postwar per capita income, the future prices of gasoline and fuel oil, further progress in making high-octane gasoline, postwar policy in levying fuel taxes to finance highway construction, and the future of the airplane. All we can say with confidence is that engineers can make good Diesel-driven automobiles if there is a demand for them. They would be better than gasoline cars in some ways and less satisfactory in others, but motorists would get used to them.

Diesel aircraft

The Diesel-powered plane is a likelier prospect than the passenger car, although it arouses heated disagreements among experts. As long ago as World War I the government worked at putting wings on the engine. The late Captain L. M. Woolson of the Packard Motor Car Company designed an aircraft Diesel engine in the early thirties, and half a dozen of the motors were successfully tested in flight. The German Junkers firm was making Diesel aircraft motors before the present war, and the Lufthansa had fifty of them in service on long-range transport planes, which they used over the South Atlantic line. The chief engineering problem was to reduce the weight of the engine, and Junkers met it with a double-action motor, in which the combustion propels two pistons at once in opposite directions. It was reported that this motor weighed one and four-tenths pounds per horsepower. The better gasoline aircraft motors of the day tipped the scale at one and three-tenths. Since Diesel fuel goes farther, this weight was low enough, claimed Junkers, so that the combined weight of engine and fuel made for greatly increased flying ranges.

Little has been heard of Diesel aircraft in the present war. In 1942 it was reported by the Associated Press that the Germans were using Junkers bombers with supercharged Diesels at high altitudes over England, but if since that time any country has used Diesels in military planes, it has been kept a dark secret. An air-cooled radial Diesel aircraft engine may be seen in the Museum of Science and Industry at Rockefeller Center in New York, and this type of motor has been recently improved by the Guiberson-Diesel Engine Company of Dallas, Texas. Among the flying Diesel's shortcomings is lack of surplus power for a quick take-off, but a number of methods are being tested to supply this kick.

Whether the motor takes to the air or sticks to land and sea, its graph is headed upward. Great progress has been made in improving other prime movers in the last half century, but with one exception, none of them has matched the efficiency of the Diesel. The mercury-vapor turbine, used in conjunction with the steam turbine, is reported to produce as much power from the fuel as the Diesel in the few installations which have been made, but its range of use is limited. The Diesel can, within its economic limitations, do anything any other motor can do, do it on less fuel and do it on cheaper fuel.

Sooner than we like to think, fuel economy may be the controlling factor in the choice of engines fed by oil wells. And when the oil wells go dry, the Diesel will keep on running. The inventor thought of this, and tested many fuels. The engine can be made to run on almost anything. Diesel used castor oil, fish oil, cottonseed oil and peanut oil. Alaskan cannery boats have used whale oil in a pinch, and in the current war, the Germans have used rectified palm oil as a Diesel fuel. The inventor also suggested the use of powdered coal as a fuel, and his chief draftsman, Pawlikowski, was still working on the plan in the thirties. And although the motor will probably never be reduced to a dairy diet, a New York engineer has actually run a Diesel on rancid butter.

Increased power output and reliability are expected from the Diesel as a result of wartime developments. Once there was occasional trouble from the highly precise injector which forces the fuel into the cylinder head; now it almost never fails. For many years Diesels have been supercharged (see next chapter) to increase power output by packing more air into the cylinder. The newest superchargers increase the power of the motor by as much as fifty per cent with little addition of weight. And there are adaptable Diesels which will burn either fuel oil or natural gas.

Among the factors which have retarded Diesel development is a shortage of Diesel repair men and a general lack of public information about the motor's advantages. Since Pearl Harbor the Government has trained great numbers of Diesel mechanics, and hundreds of thousands of machine-minded Americans who grew up with gasoline engines have been living with Diesels all over the world. These men will play an important part in the inevitable destiny of the world's most efficient prime mover.

CHAPTER SEVEN

DR. MOSS AND HIS TURBOSUPERCHARGER

On July 24, 1941, a formation of Flying Fortresses bombed Nazi shipping in the port of Brest "from a height so fantastic," according to news reports, "that the scream of their bombs was probably the first inkling the Germans had of the attack." After the bombs were dropped, it seemed an almost impossible time before the flashes were seen, reported a crew member. As for enemy interceptor planes, one man saw condensation trails thousands of feet below, where enemy fighters were searching for the unseen attackers.

This was a landmark in aerial warfare. In the constant struggle between offense and defense, the war had once more been "kicked upstairs," this time so high that requirements for fighting planes and anti-aircraft guns were altered overnight. For the first time a formation of heavy bombers had done effective work from the neighborhood of 35,000 feet. High-altitude precision bombing, a matter of hot debate in Allied aviation councils, was soon vindicated, and Fortresses and Liberators by the thousand, geared for the new high ceilings, poured across the Atlantic to bring the hail of destruction up to the crescendo of 1944.

Attached to each of the four engines of these Fortresses was a modest-looking piece of mechanism called a turbosupercharger. Without these gadgets, the bombers could not have taken their heavy loads six miles aloft. Far below that level, power would have fallen off, speed would have been reduced, and the listless plane would have refused to respond to its controls.

Two months before these Fortresses received their baptism on the European front, secret orders were given to start producing the Superfortress B-29, which in June, 1944, first sailed from a distant base to shatter Japan's industrial plants. The exhaust gases of each of its four 2,200-horsepower motors drive twin turbosuperchargers, packing air into the carburetors to send the new giants higher and faster.

The news of these bombings was eagerly received by a whimsical, bearded inventor now in his seventies—Dr. Sanford A. Moss, the inventor of the turbosupercharger. For twenty-odd years Dr. Moss, an engineer of the General Electric Company, vainly preached its merits. Inventor, engineer and press agent in one, he had hammered away at his idea with fanatical enthusiasm, but during a long period of aviation development, he was a voice crying in the wilderness.

The Brest attack was not the first occasion on which his invention proved its merit. In the early twenties, General "Billy" Mitchell used a plane equipped with it in his famous bombing demonstration of obsolete ships off the Virginia capes. Authorities who shut their eyes at Mitchell's grim lesson had no trouble overlooking a small device which helped make it possible.

So in 1938 Dr. Moss was retired, with the usual farewell banquet and oratory. He was expected to content himself with his hobbies, genealogy and archeology, the little while longer a bad heart would let him live. Then the war came and the aviation world caught up with him. With a virtually unanimous rush of insight, his former critics acclaimed his invention. Both inventor and gadget were taken off the shelf, and millions were spent on new plants to manufacture the device. Recent improvements made in airplane construction are legion, but the turbosupercharger is considered one of the greatest single aeronautical inventions to be adopted since Pearl Harbor.

When motors gasp

Anyone who has ever climbed a high mountain is in a position to understand the nature of its job. He will remember how his pace slowed down as he gasped to fill his lungs with the rarefied air. The internal combustion engine of an airplane begins to be similarly distressed when the plane ascends above 10,000 feet or so. The power of the down-stroke of the piston depends upon the weight of the charge of air and vaporized fuel which enters the cylinder before each combustion. The higher the plane goes, the lighter this charge becomes, and the more languid the punch of the down-driving piston. At 20,000 feet, for instance, the unaided motor develops only about forty-four per cent of the power which it delivers at sea-level.

The turbosupercharger restores this lost vitality. As its name indicates, the device is composed of two parts, a turbine and a supercharger. For a rough diagram of an explanation, think of these parts as two electric fans mounted side by side on the same shaft, each enclosed in a separate compartment. Think of the exhaust gases of the motor striking the blades of one fan with force enough to keep it spinning, thus creating power which the other fan uses to blow air through a tube into the carburetor. Although this illustration is little more than a symbol for an elaborate mechanism, it shows how the power of the engine exhaust, which usually goes to waste, is used to increase the weight of the charge in the cylinder, thus giving the struggling motor a new lease of life. Dr. Moss likes to remember the expression of a test pilot: that the turbosupercharger "kids the engine into thinking it's at sea level."

It was during World War I that Dr. Moss actually began work on his turbosupercharger, but his entire working life had been spent in mastering the principles of its component parts. His father was a West Coast mining engineer, and as a boy who read Jules Verne and took apart the family alarm clock, Moss naturally became curious about the machines used in his father's business. One of these was an air-compressor used to drive rock drills, and at the age of sixteen he apprenticed himself to a manufacturer who made them. He tried to improve the compressors then in use, but found that he didn't know enough about engineering methods. College was indicated. He had no money, but at the University of California they gave him a job as janitor of the machine shop. After he had swept the floor, finished his stint working on a delivery wagon, tutored a blind student and prepared his lessons for the next day, he went to the shop and plotted inventions.

Student inventor

When he was a junior—that was in 1895—he brought forth an invention that was to shape his whole career. It was a gas turbine. "College juniors usually invented gas turbines," he says. The thing looked very simple. The internal combustion engine is a good way to get power. So is the steam turbine, and its rotary action is more efficient than the reciprocal motion of the gasoline engine. So why not apply the power produced by burning fuel to a rotary device, and get a more efficient gasoline engine?

He built a model in which the power generated by the combustion of the fuel spun the blades of a circular turbine, instead of driving a piston as it does in the ordinary gasoline engine. He finished the motor and puffed up with pride as it actually ran. All was well until he tried to make the engine do some work. Then it coughed dismally and died. After some thought he discovered the trouble. To make the engine run, compressed air had to be forced into the combustion chamber. The engine generated enough power to run its own air-compressor, but nothing was left over. That, of course, was a serious set-back, but all was not lost. Moss described his experiments in a thesis, and won his Master of Arts degree. It was not until years later that he found that John Barber of England had taken out a patent for a gas turbine in 1791. "I was convinced," he says, "that Barber had stolen my invention."

Even an admirer of Jules Verne had no idea at that time of the needs of modern aviation, but in making a turbine that could be driven by combustion gases, Dr. Moss had paved the way for today's turbosupercharger. He had, so to speak, built one-half of the device which now sends planes hurtling through the sub-stratosphere. To supply the other half, all that is necessary is to turn the first idea on its head and make a turbine that will drive air. For more than half a century, Dr. Moss has been exclusively occupied with some form of bladed wheel that plays either an active or a passive role. Few people on earth know more about a turbine than he does, and his very existence at a time when he could fill a specific war need was a miracle of good fortune.

The inventor had a long and weary row to hoe before he could put his ideas to work. He went to Cornell to try to discover, among other things, why his gas turbine wouldn't deliver power, and got a job as instructor to pay his way. When the Cornell examiners looked at his Ph.D. thesis in 1903 they found a further report on his experiments with the gas turbine. Dr. Moss had operated what was probably the first turbine wheel ever run by products of combustion in the United States. The General Electric Company heard about him, and signed him up to continue his research at their Lynn, Mass., plant as soon as he graduated. From that day to this, save for the brief period of his retirement, he has seldom been absent from his laboratory.

Dr. Moss's ambitious plans for a gas turbine had to be shelved temporarily. He could not break the engine of its habit of consuming most of the power it produced, and in those days it was hard to find combinations of metal alloys that would stand up for long periods in the intense heat generated by the engine combustion. This set-back did not mean a slackening of activity, for there was plenty of work for an engineer who knew about turbines. Moss turned out a more efficient bladed wheel to compress air. It was adopted rapidly in iron foundries and blast furnaces, in illuminating-gas plants and to furnish compressed air for pneumatic tube and conveyor systems.

Airplane supercharging was far from his mind at the time, but if his life had been directed by the goddess of aviation, whoever she may be, the lady couldn't have improved the unconscious shaping of his career. During the anxious periods of testing new compressors, when the machines ran for forty-eight hours at a stretch, the designer watched over them like a mother over a sick child. These bladed wheels, when in rotation, vibrate on a definite musical note, and Dr. Moss could follow their performance by the slightest change in pitch. His ear became so sensitive to the shrill voice of the machine he had created that he could even go home and snatch some sleep. By putting his head out of his bedroom window, a mile from the plant, he could instantly detect a note of complaint.

It was logical that Dr. Moss should be put to work on the steam turbine—a mechanical first cousin of his compressors—which during his working life has revolutionized stationary and marine steam power. In testing a new turbine for the first time, it is necessary to know exactly what happens to the flow of air created, since a small stream of air flowing in the wrong direction may mean lowered efficiency. Impatient with other testing methods, Dr. Moss once picked up a bucket of whitewash and threw its contents at the exposed whirling blades. Plastered from head to toe, he pointed excitedly at a tiny white stream which betrayed the presence of an air current which hadn't been detected before. His associates still like to rib him about it, but his whitewash method, adapted to protect the experimenter, is now a standard procedure in testing stream-lines.

Later, Dr. Moss was largely responsible for putting the steam turbine into mass production. Before this, there were as many as 20,000 different ways of making a turbine, and each unit was a custom job. Dr. Moss standardized the parts, so that they could be combined in different ways to make turbines of all sizes at a great saving in machine tools. His work was invaluable to the rapid manufacture of marine turbines, but what is more important to our theme, his methods are now speeding the production of the turbosupercharger.

It was late in 1917, when plants were running with frantic speed and new ideas for war equipment were at a premium, that Dr. Moss set to work on his first turbosupercharger. A German named Schmidt had once planned a similar device, and more recently a French engineer named August Rateau had tested a supercharger based on the same principles. The Army Air Corps heard of it and came to General Electric, and by Thanksgiving Day Dr. Moss and a few helpers were busy in a little shed, the only building that could be spared.

The supercharger, minus the "turbo," was by no means new. In Diesel engines and racing cars, gear-driven compressors, operated by the engines themselves, have been used to pack a greater charge of air into the cylinder than is normally pulled through the intake at sea level. These devices are satisfactory for automotive vehicles, and with certain limitations, for airplanes, but they cannot compete with the exhaust-driven device in driving a plane to a high ceiling. Another way of giving an engine more air is to increase the size of the cylinder, but the addition of weight is a barrier to really high flying.

So the gas turbine of Dr. Moss's student days was drafted at last, and it was improved by all that he had learned through years of designing bladed wheels for other purposes. The spurting exhaust gases of a Liberty motor turned its blades. The turbine drove a high-speed centrifugal air-compressor, and the engine power leaped to new high levels. By February the government had placed an order, and in May the first turbosupercharger was taken to McCook Field at Dayton, Ohio, for an official test.

First test at Dayton

Huddled behind a barrier to ward off flying parts if the "stepped-up" engine should explode, a little group of Army aviation experts watched as Dr. Moss cautiously opened the throttle. To the 350-horsepower Liberty there was attached a fat, circular metal contraption so light that a man could carry it. Running at low throttle, the engine delivered so much added power that its probable performance at the high altitudes for which it was built was clear to everyone. As many fliers have discovered since then, if you cut wide open with a supercharged engine at sea level, the tremendous power is likely to tear the engine apart. A control device has been installed to prevent such accidents.

Convinced that Dr. Moss was on the right track, Army authorities arranged a test on the 14,109-foot crest of Pikes Peak, where the thin air would duplicate the atmosphere of what was then high-altitude flying. In those days there were no "stratosphere chambers" in which various altitudes could be simulated for test purposes. The supercharged motor, with gauges to test its performance, was mounted on a truck and driven to the summit. It was August, but the peak was bitterly cold. Beating their hands and ducking their heads against the sharp, driven snow, they got the engine started. For the first time, the engine was going through the ordeal of behaving in the upper air as though it were at sea level. Because of the difference in air pressure inside and outside, parts that had seemed strong enough wouldn't stand up. New parts were made and the test resumed.

Intent upon the performance, Dr. Moss forgot all about the whirling propeller, and his colleagues insist to this day that they had to tie him to a tree to keep him out of danger. After the party had gone through a great deal of agony, the turbosupercharger behaved exactly as Dr. Moss had predicted. Without it, the high altitude had reduced the engine's 350 horsepower to a bare 230. With the new device attached, its power was stepped up at once to 356. This meant even greater speed at high altitudes than the figures indicated, for thin air offers less resistance.

Schroeder's plunge

Soon after the mountain-top demonstration, actual flying tests got under way. Equipped with Dr. Moss's invention, Lieut. John A. Mc-

Cready and Major R. W. Schroeder, Army Air Corps pilots, vied with each other in setting new world altitude records. Schroeder nearly lost his life in one of these pioneer flights. One day in the fall of 1920 he took off in his biplane. At about 4,000 feet he cut in the whirling power-booster. By the time he had reached 15,000 feet he had attached his oxygen mask. Up he went in a steady climb, passing the 20,000, 25,000 and 30,000-foot marks. As far as the engine was concerned, he was still at sea level. Intoxicated with the performance of the supercharged motor, he kept on climbing. But he had miscalculated his oxygen supply. The turbosupercharger could kid his engine, but Schroeder couldn't deceive his lungs. The tank was empty. He turned purple and went out like a light, and the plane plummeted downward. By some miracle he half recovered at 3,000 feet, righted the plane and landed safely. He was rushed to the hospital with badly wrenched internal organs. His barograph record told the story. He had climbed to 36,130 feet, and he had fallen six miles and a quarter.

Other flights made during the twenties clearly established the turbosupercharger's spectacular merits. Dr. Moss never went along on these trials. "If something goes wrong with the supercharger, I can't get out in the air and fix it," he said, "so what's the use?" Once at an air field his colleagues gravely told him that he was needed in the flight. He managed to obtain a telegram from his company, strictly forbidding him to leave the ground.

In spite of the success of these tests, the big men of aviation would not admit that Dr. Moss had anything more than an interesting toy. After the Armistice was signed, work on war machines of all sorts had slumped to nothing. When the Lynn plant swung over to peacetime production, he was left with a small shed and a couple of assistants. Once it was decided to tear down the shed, which was considered unsightly. He planted trees in front of it to make it more attractive. With unquenchable enthusiasm he buttonholed everyone concerned, focused his pointed Van Dyke and sparkling eyes and talked supercharging.

He explained that his device was not merely a war weapon, that it would affect the whole future of aviation. His hearers listened politely —and turned to other matters.

Dr. Moss has a policy about matching coins which may help to explain his optimism and tenacity. He always carries a pocketful of quarters, and never misses a chance to risk a few of them. It isn't gambling, he is careful to explain—it can be shown mathematically that the odds always even up in the long run. His definition of a superstitious man is one who cannot bring himself to act upon the belief that no matter how the quarters have been falling, what has gone before has nothing whatever to do with the next pitch. And no matter how many executives and generals looked at their watches when he explained the merits of his pet contrivance, he never doubted that the odds would eventually swing in his favor.

Although other research problems claimed his attention, Dr. Moss found time to make constant improvements in his device. The failure of turbine blades, which are under a terrific strain in operation, had always been a problem. Driven by exhaust gases which may have a temperature as high as 1,500 degrees, the tips of the small turbine blades are red-hot and glow in the dark, but the inner portion of the blades do not get as hot. With the turbine revolving at 25,000 revolutions per minute, each of the blades, weighing less than one-fifth of an ounce, is subjected to an outward pull of about 700 pounds.

Super-metal developed

It takes a super-metal to absorb this punishment. Such a metal must be capable of being softened with heat in order to fabricate the blade, yet the blade must not soften or change in shape when its parts are subjected to varying high temperatures by the exhaust gases. Fortunately, the art of metallurgy has gone a long way in recent years; otherwise we would have no turbosupercharger. Research men found that an alloy called Vitallium, which was used to fill teeth, retained its strength when superheated. This alloy, which contains chromium, cobalt and molybdenum, now satisfies the stiff requirements of the turbine blade.

The gear-driven supercharger

Aviation soon accepted supercharging, but somewhat ironically, it was the gear-driven supercharger, to which Dr. Moss also made important contributions, which first stole the show. The idea of using power from the motor's crankshaft to run a compressor to pack more air into the motor to develop still more power may seem like lifting one's self by the bootstraps. But we have seen in the discussion of high-octane fuel that additional cylinder compression yields far more power than is needed to force the piston up, and gear-driven supercharging also pays off handsomely. In its simpler form, the gear-driven device will restore full sea-level power up to 12,000 feet or so, and it was followed in the early thirties by a two-speed supercharger, which enabled the pilot to shift gears in his upward flight and thus increase the speed of the compressor to compensate for the increasing thinness of the air. This type of supercharger is widely used in fighting planes and has played an important part in boosting their effective ceilings. But the device works most efficiently only at the altitudes for which it is "set," while the flexible turbosupercharger automatically regulates itself to the altitude, keeping the air pressure in the intake chamber, and therefore the engine power, the same as that at sea level. Recent progress in this field has not been announced, but at the time of the bombing of Brest, planes with turbosuperchargers delivered sea-level power at 30,000 feet, and while power fell off thereafter, they were able to operate as high as 50,000 feet.

This performance was not generally foreseen in the late 'thirties. Some engineers had not outgrown an old prejudice against devices which revolved at high speeds, and others thought that the turbosupercharger's hot blades were a fire menace. So Dr. Moss was retired, his invention still unutilized. Then bombs started falling, and suddenly the most important thing in life was to make planes which would go faster and higher and carry greater loads. The gadget born in a shed soon filled acres of factory space.

Today there are eight turbosuperchargers in every Superfortress, four in every Fortress, two in every Lightning and one in every Thunderbolt. In addition to giving sea-level engine performance at high altitudes, the device has saved many a pilot from death. When at a lower level a pilot finds an enemy fighter on his tail, he can adjust the device to increase the flow of air and thus obtain a sudden burst of speed to carry him out of danger.

Supercharged cabins

The importance of the turbosupercharger in military flying, where the top dog has the advantage, is obvious, but high flying is also destined for an important role in civil aviation. Experts look forward to a day not far distant when airliners with supercharged engines will zip across the continent in the stratosphere in six hours or less. Higher speeds will be reached because of lowered air resistance, and high altitudes will be safer, for the planes will fly far above the storm clouds and mountain peaks. Use of the upper air will pay off in flights which are long enough to justify the expenditure of fuel and time needed to climb "upstairs" and down again.

But before stratosphere traffic can be established, engineers must turn from the engine, whose breathing needs they have cared for, and consider the human being, who has been left behind in the aircraft's perpendicular progress. From 12,000 to about 30,000 feet, the oxygen tank and mask will supercharge the lungs, but above that level, various distressing and sometimes fatal symptoms set in because of decreased air pressure on the body. Escaping nitrogen makes the blood bubble like ginger ale. At 40,000 feet, abdominal gases expand four times in volume. The powers of observation diminish, and reaction time is slow.

For many years there have been attempts to "supercharge" the human body. Wiley Post and others went aloft in so-called "undiving" suits—cumbersome body envelopes which were blown up like balloons to maintain low-level pressure. Lieutenant Harold Harris, another early experimenter, set out for the sub-stratosphere in a kind of pressurized tank. It worked well on the ascent, but in the downward flight the reversing mechanism failed to function, and when he landed the pressure in his tank corresponded to 9,000 feet below sea level. This gives an idea of the problems involved.

The answer has been found in tightly sealed cabins supercharged by means of Dr. Moss's invention. As a result of work done by Major Carl Greene and others, an experimental Lockheed Electra plane was successfully tested in 1935, in which both engines and members of the crew were sustained at high altitudes by the turbosupercharger. Each exhaust-driven turbine drove two impellers, one to maintain air density in the carburetor, the other to supply the cabin. Since the altitude threshold at which people need supplementary oxygen is not reached before 10,000 feet, pressure consistent with 8,000 feet was maintained in the cabin. After further experiments, the Boeing Stratoliner, predecessor of the Flying Fortress, became the first commercial plane with a supercharged cabin.

The latest triumph is the pressurized cabin of the new Superfortress, which enables crews to fly to and from their targets in comfort at high altitudes. Over the target, the cabin is "depressurized" to the density of the surrounding air, and crewmen put on their oxygen masks. Otherwise, enemy flak or interceptor projectiles might cause sudden deflation and acute oxygen need. After the big plane leaves the danger zone, cabin pressure is restored and the men remove their masks.

Designing this pressure cabin was a complicated engineering job.

To begin with, the cigar-like fuselage was so designed because a cylinder offers greater resistance to internal air pressure than any other suitable shape. During an early test, a waist gunner leaned against a "blister" and it blew out. Driven by the compressed air rushing to escape from the hole, the gunner followed, and managed to land safely thousands of feet below. So the blisters were reinforced. The pressure can be increased to counteract the deflating effect of small bullet holes, and the cabin is equipped with special pads for plugging up larger openings. Minus the features born of war's necessities, the pressurized Superfortress offers a fascinating pre-view of the upper-level flying of tomorrow. And the heart of the whole system is the turbosupercharger, which pours the breath of life into both motors and men.

CHAPTER EIGHT

A NEW PRIME MOVER—THE GAS TURBINE

For the last three years, civilians in certain parts of England and the United States have been occasionally startled by aerial apparitions which streak through the sky with comet-like speed. Glimpses of these ghostly phenomena have always been from the rear, for there is no noise like that of the conventional airplane throb to herald their approach. As they pass overhead and fade into the distance a curious sound is heard. Some describe it as a whistle, while others liken it to a boiling teakettle. Meanwhile, planes have been seen on the ground with open maws and no propellers, and a number of aviation fans had come to certain conclusions long before the Army announced last year that an airplane driven by jet propulsion—an idea long filed in the same pigeonhole with moon-bound rockets—was at last an accomplished fact.

The jet-propelled plane is the most dramatic application of a new prime mover which now rises to challenge older sources of power—the gas turbine, which, according to Dr. Sanford A. Moss, college juniors have been inventing since time immemorial, without being able to make it work. Some form of the gas turbine has existed on paper longer than the Christian era, and patents relating to the principle run into uncounted thousands. Now at last the thrill of life has animated its fabulous innards. It works, and, like all other prime movers, it has potentialities of power which may affect not only the world of machines, but may, like the steam turbine and the reciprocating internal combustion engine, bring about profound changes in the life and habits of man.

Great claims are made for this prime mover as a motive power for ships, factories, locomotives and electric generating stations, and some of America's largest and most competent manufacturers are pushing these plans toward fruition. Engineering opinion of the motor ranges from boundless enthusiasm to sober skepticism, but one thing is sure: the gas turbine is no longer an inventor's will-o'-the-wisp. It is in production and will eventually be on every job for which it seems suited, and we will soon have a fair idea of where it belongs in the hierarchy of power.

We already know what it can do in the air. On a diet of kerosene, it can drive airplanes between 500 and 600 miles an hour—about 100 mph faster than they have ever gone before. It has little noise and no vibration. It uses no propellers, no cooling system, no pistons or crankshafts, and has only a few lubricating points.

Beautiful simplicity

The gas turbine is an engine of beautiful and incredible simplicity. The details of the aircraft motor now being produced are unknown, but the principles of such a motor are common knowledge, and many types have been designed and publicized in Germany, Italy, Sweden, England and Switzerland. They differ widely in appearance and appurtenances, but are all alike in that they heat air by burning a fuel, and utilize the power of the released, expanding air to drive the plane. In its simplest form, a gas-turbine, jet-propulsion motor may be roughly described as a big tube with a large opening in front and a small one in back. It has only two moving parts. In front is a rotating air compressor, and behind it, mounted on the same shaft, there is a turbine. Air drawn in through the front is compressed, then released in a combustion chamber to supply oxygen for burning the fuel which is injected into the chamber. The hot, expanding gas, seeking an outlet, spins the blades of the turbine, thus giving up a large part of its power to drive the compressor. Back of the turbine, the tube tapers to what is known as a "convergent-divergent" nozzle like that of a garden hose in which the opening narrows down to a small neck, then flares out to make the liquid spurt. When the nozzle end of a garden hose, released in use, writhes like a reptile, it furnishes an example of the power of jet reaction. Somewhat similarly, in the jet-propelled plane the expanding gas spurts through the nozzle and drives the craft forward. In many jet-propulsion designs, a small independent motor is needed to start the compressor, and a spark plug to start combustion, but once the motor is under way, these auxiliaries are turned off.

Strikingly similar systems of jet propulsion are used by the cuttlefish, the octopus and the squid. Behind the head of the giant squid there is a circular opening which looks like a collar, through which the squid draws water into a special reservoir in his body. When the squid wants to go somewhere, he expels the charge of water through a muscular tube, and the jet reaction shoots him forward with lightning-like speed. He even has a valve on the intake to keep the water from going the wrong way.

The first human jet-propelled flight to attract public attention took place in Italy a few days before Pearl Harbor, and because the experimental Caproni-Campini plane took two hours and a quarter to cover 168 miles, it was considered a fumbling failure, which in many ways it was. It had no gas turbine, but used a radial gasoline engine to run its air compressor. In one design, whether by conscious imitation or otherwise, there was a collar-like air intake around the plane's nose, similar to the squid's water-intake device. The compressed air then flowed into a combustion chamber where fuel was burned, and the expanding gas passed through the discharge nozzle, using all its power to push the plane. Thus the plane had two power plants. It was a heavy, bulky and complicated arrangement, and it had most of the troubles of maintenance of a conventional plane with few added advantages. But it actually flew without a propeller, and it helped to publicize the fact that the propeller is becoming a limiting factor in airplane speed. As engine power has been boosted, propeller blades have been made larger and longer to absorb the added power, and heavy, long-legged undercarriages are needed to keep the blades clear of the ground. One attempted solution is to mount two "props," rotating in opposite directions, on the same shaft. But no matter what devices are used, turbulence set up by the propeller tips as they approach the speed of sound (750 mph) defeats the motor and changes values which prevail at lower speeds.

"Visionary" Frank Whittle

Eleven years before his first jet-propelled plane took to the air, a young Englishman named Frank Whittle set forth in a patent his own ideas of a propellerless craft. Whittle, the son of an inventor, had been building model planes since he was a boy. The slide rule is his bible, and with its aid he had checked every conceivable fact about his proposed plane. Since he was only twenty-two, manufacturers who turned him down called him a "young visionary." Had he been older they would have called him an old visionary. Nothing was done about his plan, and Whittle joined the RAF, rising through the ranks to the position of Group Captain. In 1933 he interrupted his military career to study mechanical science at Cambridge, where he won first-class honors. He also discussed his idea with other young airmen who had open minds. Two of them caught his enthusiasm and raised funds to build the first known gas-turbine jet-propelled plane to emerge from the blueprint stage. The work was done in a vacant foundry near Gloucester. Curious natives, listening to the noises that emanated from the locked doors of the factory, concluded that Whittle and his men were making sausage machines. In 1937 his first engine passed a successful bench test, and the government immediately put him on special duty for further research. The first successful flight of the revolutionary plane took place in May, 1941. The weird monster furnished plenty of surprises. Policemen who were told to guard it overnight made the awful discovery next morning that the propeller was missing, and they had thrown a dragnet over the countryside before they learned that this plane had no propeller. When the plane was taken by truck to the airfield, a false nose with dummy propeller was used to conceal the secret from onlookers. When the plane was being warmed up, a pilot ventured too near the air intake and was pulled into the duct and held there until the motor was stopped. When an important official walked by the spurting exhaust jet his coat was torn from his back and his hat was blown two miles away. But the secret was so well hidden that previous to the public announcement in January, 1944, not even Captain Whittle's wife and children knew what he was working on.

The United States Army Air Forces were given full details early in the engine's development, and soon after the Whittle plane made its first flight, mysterious packages began to arrive at the Lynn, Mass., plant of the General Electric Company. They contained parts of a jet engine. They were soon followed by Captain Whittle, who called himself "Whitely" and concealed his identity from everyone but a few engineers while he assisted in the design and construction of the American jet plane. While the motor was being built, the Bell Aircraft Company, with equal secrecy, constructed a plane to house it. The American plane has two jet motors, one on each side of the fuselage, while the English plane has only one. The first American jet-propelled flight took place on October 1, 1942, and since that time, hundreds of routine flights have proved beyond doubt the plane's reliability. The Army's opinion of it may be gathered from the fact that last year General Electric devoted a plant of more than 600,000 square feet of floor space to the production of jet motors.

No complete description of Captain Whittle's plane has been released at the time of writing, but certain general facts about performance are clear. The jet-propelled plane can use almost any form of cheap oil fuel, but it uses a much greater weight of fuel per horsepower than the conventional aircraft motor with its high-octane gasoline fuel. As compensation for the added fuel load, the Army Air Forces report that it will carry more weight for the same amount of wing space than the conventional plane. The faster the jet plane goes, the greater its propulsive efficiency. It reaches its maximum efficiency when the forward speed of the plane is equal to the backward spurt of the expanding gas which drives it, and this optimum speed—better than 700 mph—would leave a conventional plane standing still. We have seen that the propeller-driven plane falls off in power as it gains in altitude, and that superchargers are needed to help restore the lost vitality. But the jet-propelled plane is more efficient at high altitudes than in the denser atmosphere of sea level. In the thin upper air, expansion of the gas through the nozzle is facilitated because of lower outside resistance, so the speed of the plane is increased.

Yet Whittle's jet-propelled plane will always be limited to altitudes within the earth's atmospheric blanket, since it draws in oxygen to support combustion of fuel. Only the rocket plane, which does not exist except in theory, can go higher. This much-heralded sky vehicle has been frequently confused with the gas-turbine jet-propelled plane. While both are driven by the reaction of expanding gases, the rocket plane, as Dr. R. H. Goddard and others have conceived it, carries its own oxygen and therefore needs no air compressor or turbine, and is at home—theoretically—in interplanetary waste spaces beyond the earth's atmosphere. The jet planes now flying are not rocket planes, and the attention of headline writers is directed to the fact that "jet" is a shorter, as well as a more accurate word.

Germany's "secret weapon" of 1944, the pilotless, bomb-carrying craft with which she bombarded London, is not a rocket plane, but belongs in the jet-propelled category, since it requires atmospheric oxygen for the combustion of its fuel. Although popularly called a bomb, this device is really a "throw-away" jet-propulsion airplane, stripped of all parts, instruments and protective armor needed by a human pilot, and with its design strictly subordinated to the function of delivering the bomb at the desired destination. It is said to be equipped with spherical containers of compressed air as well as an ingenious air-intake device, and is kept on the course by a gyroscope in the tail. There seems little doubt that larger flying bombs, directed by radio, could travel much longer distances.

To return to the jet plane, which is powered by a gas turbine, it has a number of obvious advantages over the conventional airplane. Kerosene, Diesel oil, and other possible fuels are safer than gasoline. No warm-up period is required. Full power is obtained thirty seconds after the motor is started. The low pressures in the gas-turbine system make for light construction. In a single-seater fighter plane, there is no motor to block the view of the pilot. Lack of vibration and reduced noise play their part in reducing pilot fatigue, and the plane's comparative silence lends itself to surprise attacks. There are reports that English birds have been sucked into the compressor because of this feature, but no substantiation can be found for further statements that the birds are ejected from the rear cooked and ready for the table.

Officers of the Army Air Forces report that despite the radical nature of the new plane, the only problem of training pilots is to teach them to fly a simpler plane with fewer instruments, and one may safely assume that this simplicity also means a reduction in man-hours in manufacture and maintenance.

Power for "flying wing"?

Since airplanes are built around motors, and the motor's size, shape, weight, speed and other characteristics have an all-important influence on plane design, it would not be surprising if jet propulsion dictated the creation of a completely new airplane. For several years, experimental "flying wings" have been tested, in which the cabin, engine nacelles, tail and all other protuberances have been submerged in a single thick wing. With crew, passengers and cargo as well as power units all concealed in one smooth, unbroken wing, greater speed or more miles to the gallon of fuel are assured, report aviation experts. G. Geoffrey Smith, M.B.E., in his recent book, *Gas Turbines and Jet Propulsion for Aircraft,* makes the following suggestion:

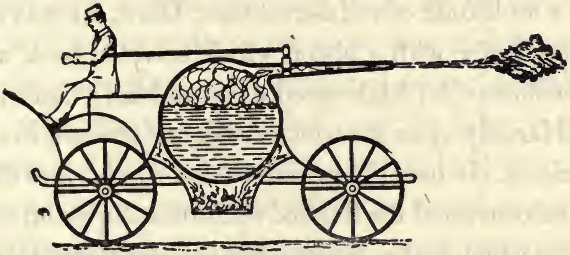
"Thus if it be accepted that progress with the 'all-wing' design has been such that it is now as stable and maneuverable as conventional aircraft, the equally modern power plant of compact circular shape with few excrescences as represented by the turbine-compressor combination would suggest itself as an ideal form of power unit for development with an aircraft of this character. It has been estimated that a flying wing has from thirty-three and one-third per cent to fifty per cent less total drag than a normal type, which implies that considerably less horsepower is needed to attain the same speed. Since a jet propulsion unit is considerably lighter in weight than an equivalent reciprocating engine with its many auxiliaries, a double advantage is suggested on paper by marrying the flying wing to the gas turbine. It seems a logical development with attractive possibilities."

The great speed of the jet plane makes it conspicuously eligible for military use, but civil airlines the world over are exploring its possibilities for high-level, transoceanic passenger service, and the British Air Ministry has approved a design for postwar trans-Atlantic use. Meanwhile, many engineers are working to improve the gas turbine, and the first machine to profit by an increase in its efficiency will be the jet-propelled plane.

While the new plane demonstrates one of the most spectacular uses of the newly perfected gas turbine, firms like Westinghouse, General Electric, Elliott, DeLaval, and Allis Chalmers are investing quantities of money and work on the earth-bound future of the motor. In the air, the only purpose of the turbine is to spin the air-compressor, and the surplus power in the expanding gas is utilized in the forward-pushing jet reaction. In the ground version of the motor, the jet device is eliminated, and the turbine is designed both to take care of the power needs of the compressor and to convert the residual energy into power for turning wheels. It would be possible to mount such an engine in an ordinary plane and make the turbine spin the propeller—in fact, such designs exist—but according to the Whittle school of thought, such an arrangement would add weight, reduce mechanical efficiency and be generally superfluous. On the ground, the surplus turbine power does the work, and it is this type of engine which is now being developed in varied designs to drive locomotives, ships and stationary machinery.

Ancient origins

Notions about gas turbines and jet propulsion rattled around in the minds of inventors long before the gasoline engine was thought of. Historians usually trace the origin of these ideas to Hero of Alexandria, who about 130 B.C. built a toy altar with a firebox beneath it. Hot air passed through a radial system of tubes, forced them to rotate, and gave the illusion of life to symbolic figures of men and women. Hero also built a kind of steam engine which operated by the jet reaction which now drives planes. In 1680 Sir Isaac Newton built a model of a



Sir Isaac Newton's idea of a jet-propelled vehicle. Reaction of escaping steam was supposed to push carriage forward.

jet-propelled horseless carriage. Steam generated in a spherical boiler escaped through a jet pointed rearward, and the reaction was supposed to drive the vehicle. The jet could be turned for steering purposes—a feature which is now incorporated in some of the jet airplane designs.

The first working gas turbine of sorts seems to have been the seventeenth-century "smokejack." A crude turbine mounted in the chimney above a fireplace was turned by the pressure of rising hot air, and through a system of gears it rotated a roasting spit. Then in 1791, John Barber of England took out the first patent for a gas turbine. It was an approach to the engine of today in that it provided for a compressor, a combustion chamber and the turbine. So far as we know, the motor was never built, and little is known of its possibilities except that it could not have been practical in view of the limited mechanical development of the period and the metals then available.

Since that time a host of engineers have improved the component parts of today's gas turbine, many of them with no thought that they were helping to create a new prime mover. Air compressors, for instance, have a multitude of industrial uses. Once, air was compressed by a pumplike device with a piston which traveled back and forth, a method too inefficient for high-speed devices. Man's material progress has depended largely upon the trick of taking a straight line and bending it into a circle. He bent the primitive sled-runner into the more efficient wheel; he converted the flat-bed reciprocating printing press into the rotary press which makes modern newspapers possible, and he took the linear force exerted by the electromagnet and made it turn a wheel. So rotary compressors were built, and it is a comparatively new development in this line, the axial-flow compressor, which has broken one of the bottlenecks in gas turbine design and made the long-deferred motor a practical tool. This funnel-like compressor, bristling with whirling blades, packs air into smaller and smaller volume as it passes through it.

Knowledge gained in building the steam turbine (another "circle" which out-performs the straight line of piston action) helped to build the gas turbine, but the final touch was contributed by aircraft engineers' discoveries about the behavior of air when it hits a wing or propeller. As a result, each one of the many small turbine blades of the new engine has a shape similar to that of a propeller.

First American motor

The first stationary gas turbine in the United States was set to work as long ago as 1936, but its possibilities were not generally recognized and it attracted little comment except among technical men. In the Houdry catalytic oil-refining process, compressed air is used to burn the deposits of carbon from the beds of clay-pellet catalysts through which vaporized oil is driven to hasten the production of high-octane gasoline. So these refineries already possessed two of the major elements of a gas turbine motor—the air compressor and the combustion chamber. The potential power in the hot gases which remained after the pellets had been burned clean and prepared for re-use was being wasted. So a turbine was added to the procession of devices. By turning the turbine, the expanding gases produced power enough to run the compressor, and there was power left over for other purposes. Now more than twenty of these turbines are running in Houdry plants, with an impressive saving of power that otherwise would go up the flue.

The gas turbine's leading modern pioneer is the Swiss firm of Brown, Boveri and Company, which has set the new motor to work generating electricity and driving a train. In war time, steam-driven electric power stations are extremely vulnerable. They are bulky, conspicuous targets, and if falling bombs disrupt their water supply they are paralyzed. The Swiss thought of these things in the late thirties, and Brown, Boveri were consulted about an emergency gas turbine plant for the city of Neuchâtel. The 4,000-kilowatt bombproof underground plant, which takes up about one-third the space needed by a comparable steam plant, has been operated since 1940. It uses no water and is simple to repair. The following year the world's first gas-turbine-electric locomotive was put on the tracks by the same firm. The compact, light-weight engine turns in a good performance at eighty miles an hour and is almost twice as efficient as a steam locomotive.

The Swiss locomotive may turn out to be a trail-blazer. Engines of this type may pull trains in the United States after the war. The Allis Chalmers Company of Milwaukee has drawn up blueprints for a 5,000-horsepower gas-turbine locomotive, equipped with the "fluid drive" used in some automobiles, and General Electric and Westinghouse are planning experimental gas-turbine-electric units. Such engines will take up much less space than steam or Diesel locomotives. Instead of depending upon cooling systems, this engine is actually insulated to keep heat from escaping. A motor without a thirst, it will save the time

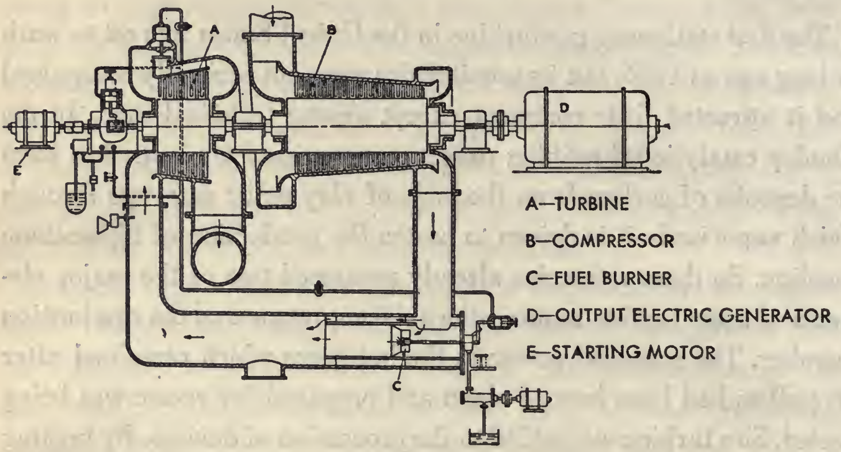
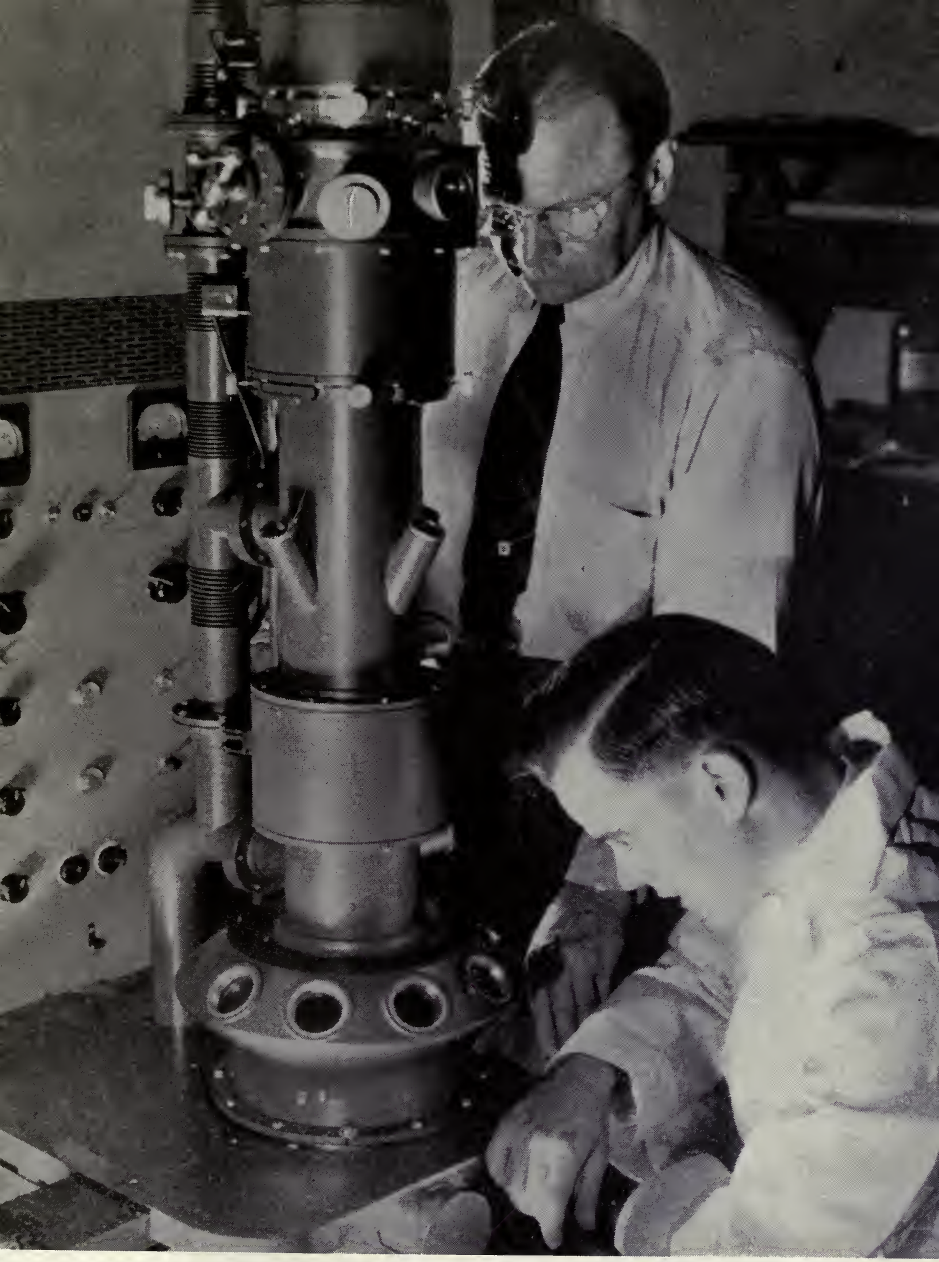
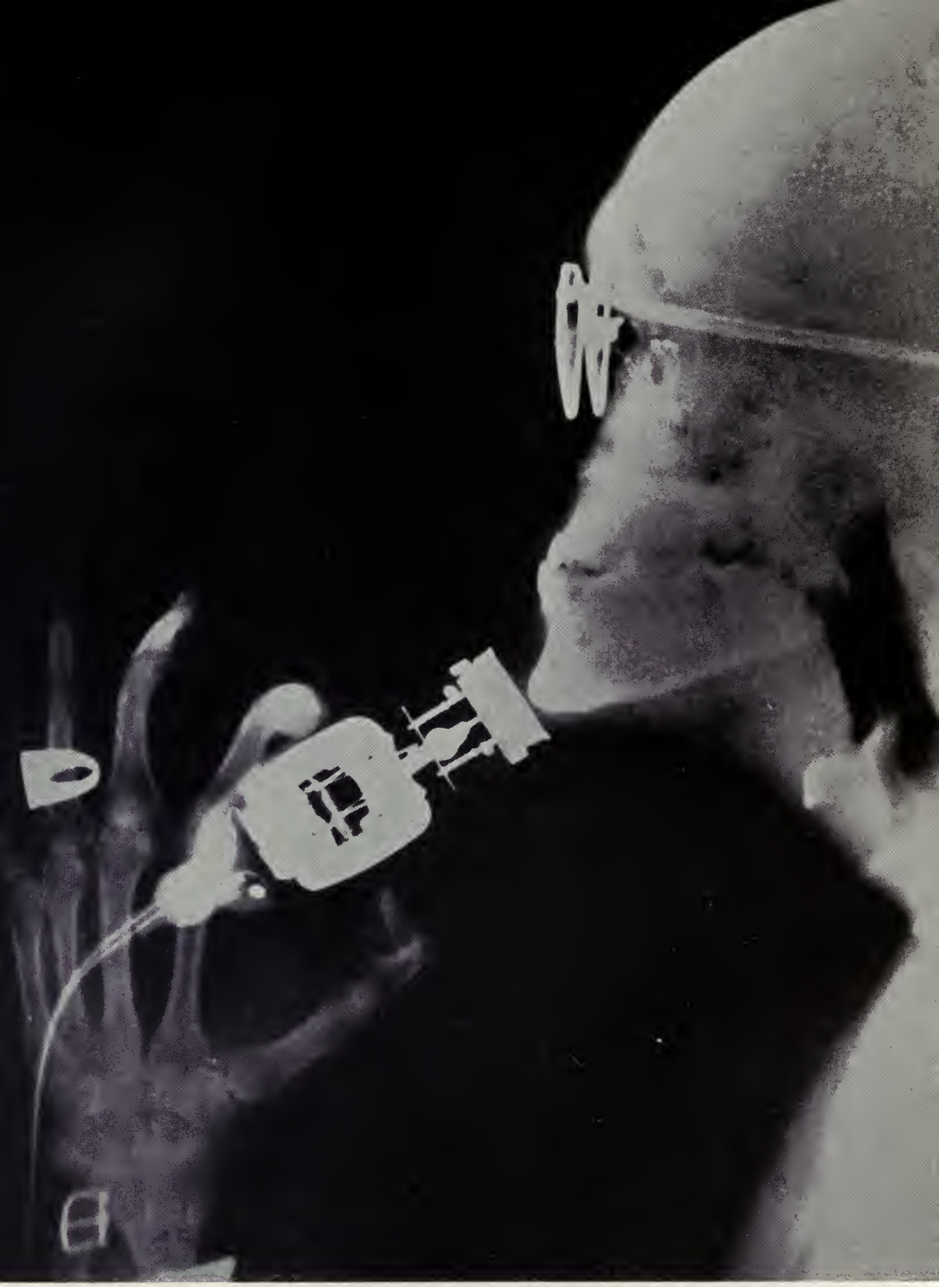


Diagram of the gas turbine now being built for ships and locomotives. Air is drawn in as shown by arrow at top, compressed by whirling compressor (B), rushes to fuel burner (C) where it furnishes oxygen for combustion of oil. Hot, expanding gases turn turbine (A), and escape through exhaust after giving up power. Turbine drives compressor, mounted on same shaft, and with remaining power drives electric generator (D). Jet plane motor is similar in principle, except that surplus power is used by releasing gas through nozzle, pushing plane forward. (Courtesy Allis Chalmers Manufacturing Company.)



(*Courtesy Radio Corporation of America.*)

The electron microscope, which is opening new frontiers in research, is shown by Dr. V. K. Zworykin and James Hillier, leaders in its development.

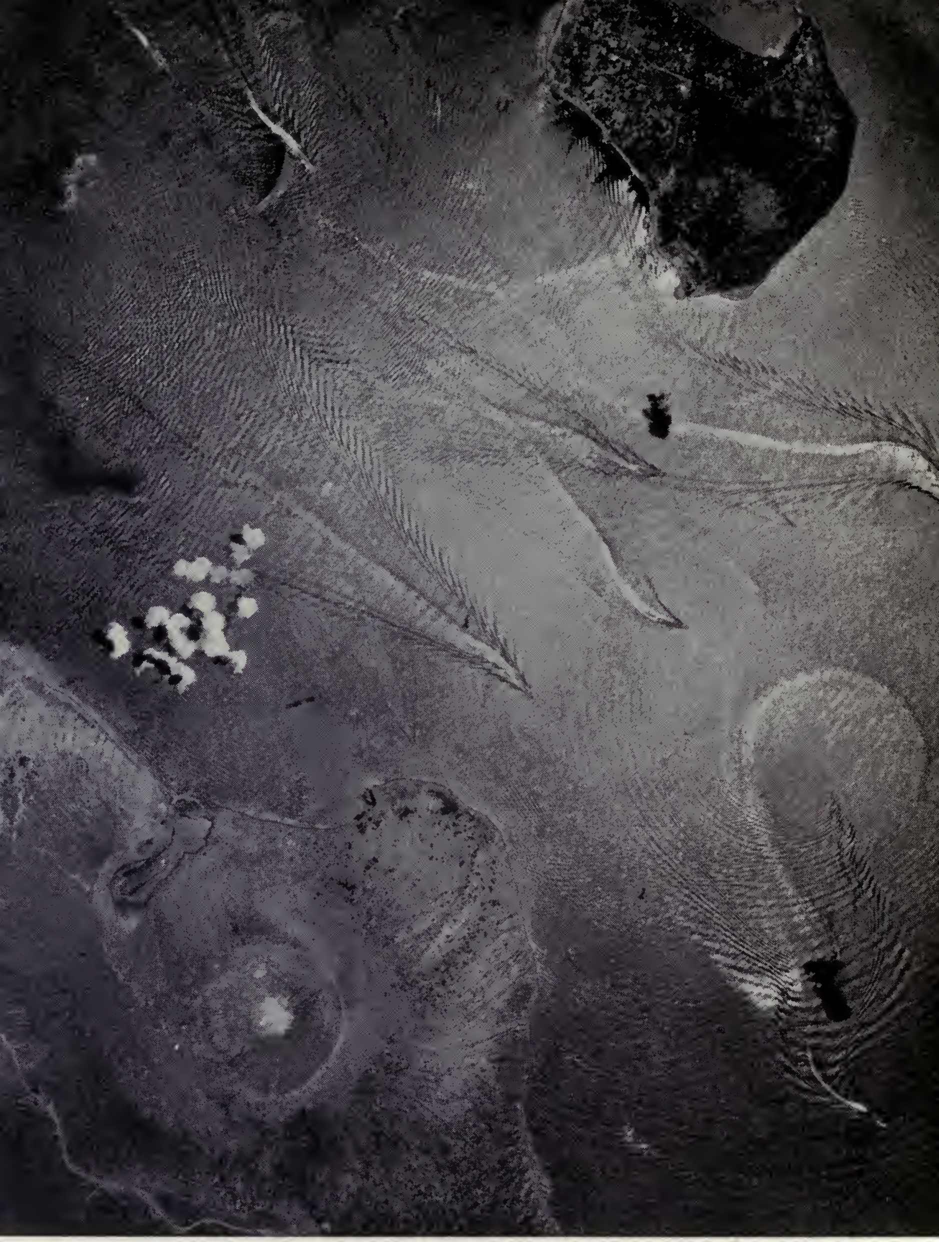


(*Courtesy Westinghouse.*)

Portrait of *homo sapiens,* shaving. This X-ray, taken at 1/1,000,000th of a second, "freezes" motion of electric razor, whose motor is making more than 116 revolutions per second.

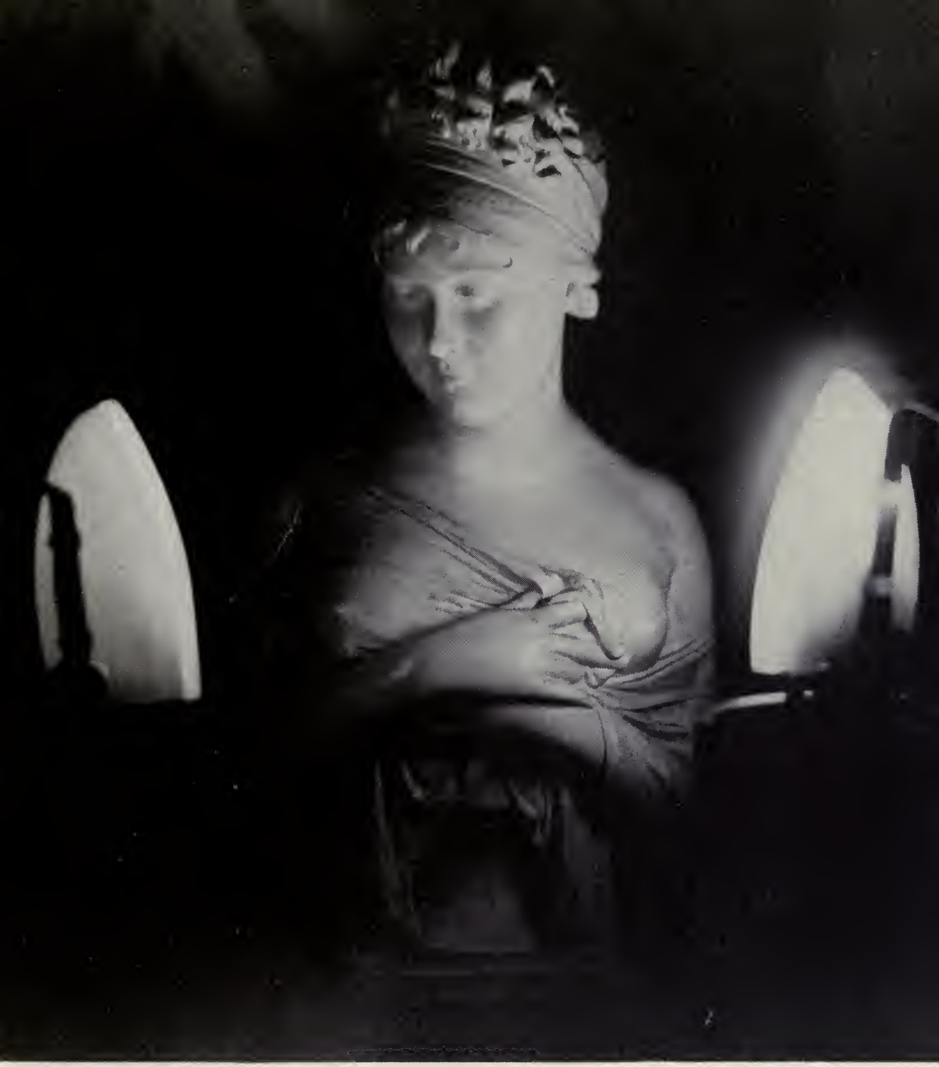
(*Courtesy Westinghouse.*)

Girl breaks light-beam and electronic tubes automatically signal tiny motor to turn on the water. One of hundreds of tasks now performed by harnessing the elusive electron.



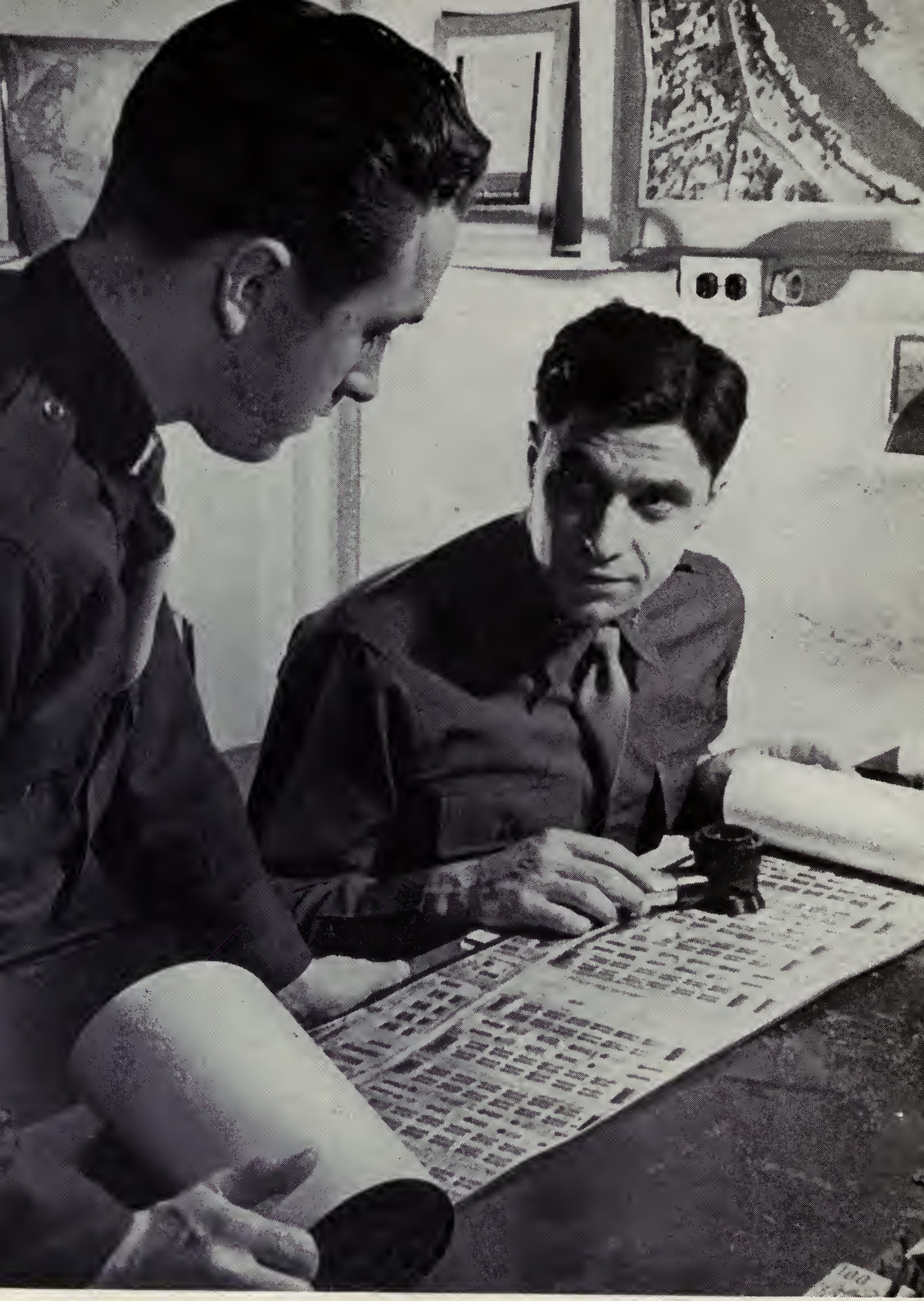
(*Courtesy U. S. Air Forces.*)

White puffs at left are bursting bombs; weird arrow-head designs are wakes of fleeing Jap ships in Rabaul Harbor. Millions of these aerial photographs guide our fighters and report results.



(*Courtesy Eastman Kodak Company.*)

Infra-red rays from ordinary electric flatirons illuminate the marble lady for this photograph taken in the dark with special film sensitive to the long infra-red (heat) waves.



(*Courtesy U. S. Army Air Forces.*)

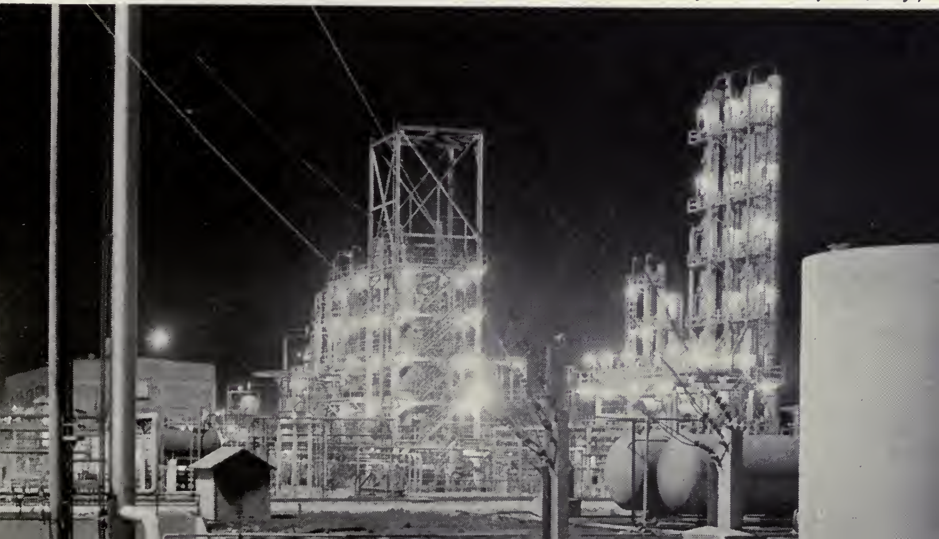
Continuous strips of enemy terrain 200 miles long are photographed with the new shutterless camera now used in all war theatres by America's "flying spies."

(*Courtesy Westinghouse.*)

"Daylight in tubes" provides strong, glareless, shadowless illumination for the great army of draftsmen in American war plants.

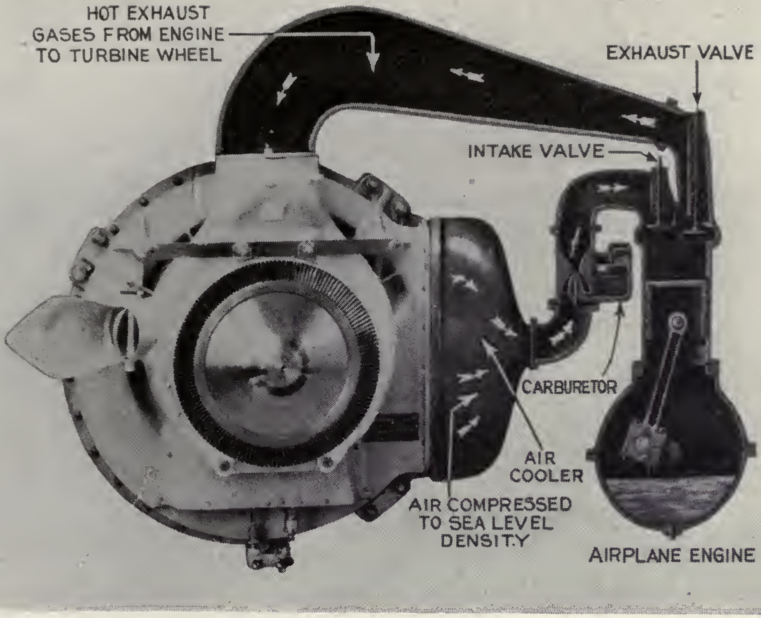
"Chemical rubber trees" in a great refinery forest, where petroleum and coal are converted into rubber for tires.

(*Courtesy Standard Oil of New Jersey.*)



(*Courtesy Standard Oil Company of New Jersey.*)

One of America's great new battery of "cat crackers," indispensable to the swift production of high-octane gasoline, man-made rubber and toluene for explosives.

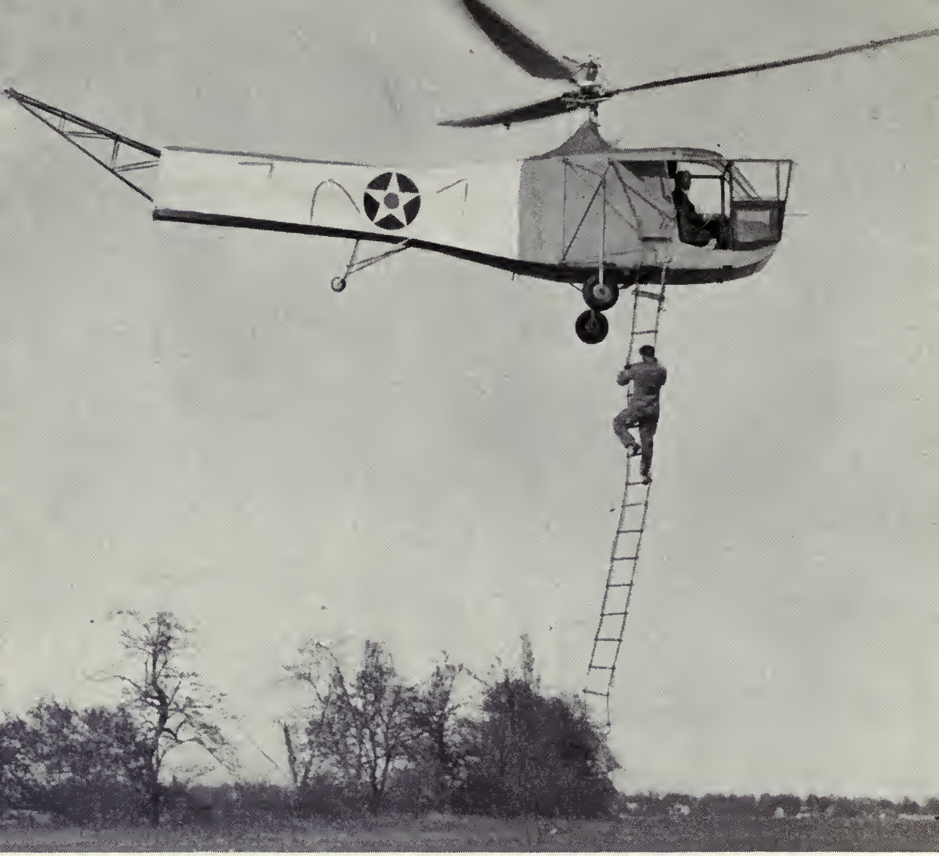

HOT EXHAUST GASES FROM ENGINE TO TURBINE WHEEL
EXHAUST VALVE
INTAKE VALVE
CARBURETOR
AIR COOLER
AIR COMPRESSED TO SEA LEVEL DENSITY
AIRPLANE ENGINE

(*Courtesy General Electric Company.*)

Diagram of turbosupercharger. Exhaust gases spin turbine, packing air into carburetor to maintain power at high altitudes.

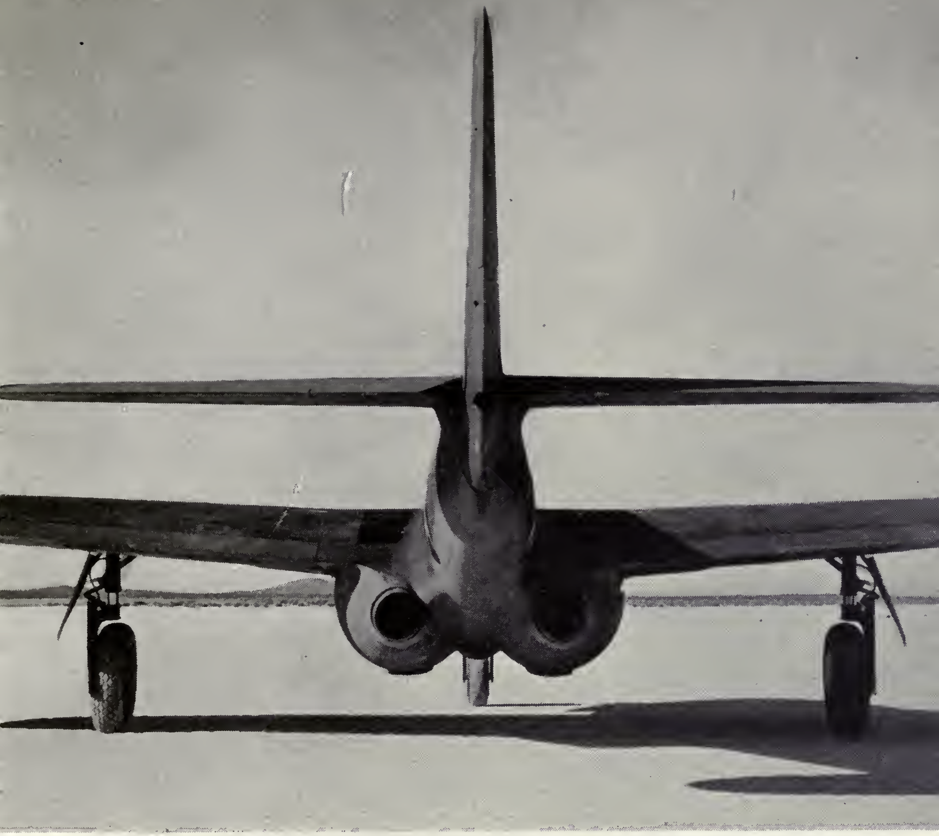
Diesel-electric locomotives are supplanting steam because of greater efficiency, cheaper maintenance and jerkless acceleration.

(*Courtesy General Motors Corporation.*)



(Courtesy Sikorsky Aircraft.)

The obliging helicopter hovers like a hummingbird while the pilot drops a rope-ladder and takes a passenger aboard. This trick has been used to rescue soldiers stranded behind enemy lines.

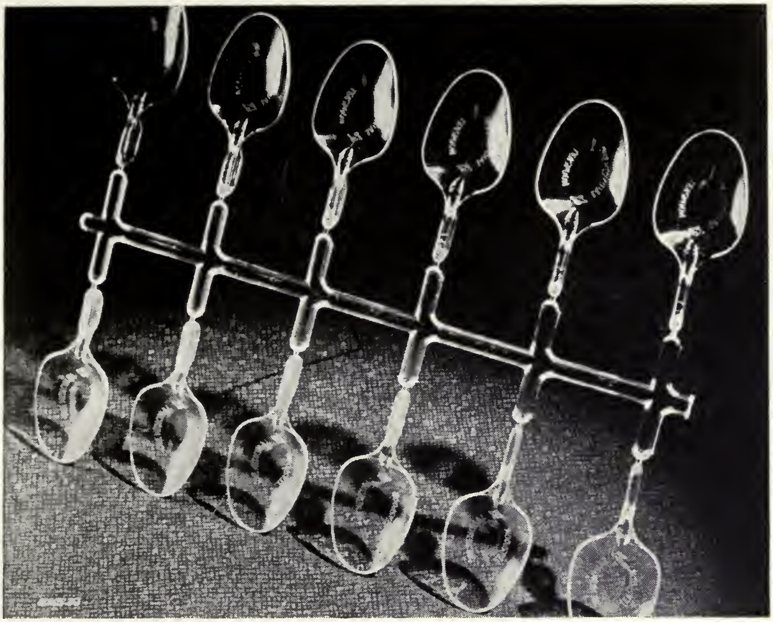


(*Courtesy General Electric Company.*)

America's fast new jet-driven fighting plane needs no propellers. The reaction of hot, expanding gases, spurting from the two apertures in the rear, force plane forward.

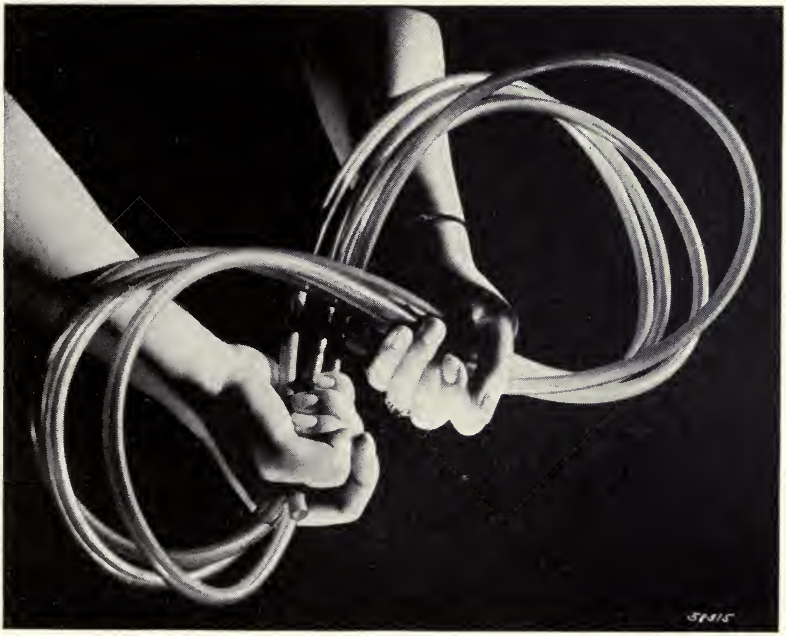
(*Courtesy Standard Oil of New Jersey.*)

Rubber from oil wells, created in great steel towers and vats, first sees the light of day. Operator holds handful of curds which will soon become sheets of solid rubber.



(*Courtesy Dow Chemical Company.*)

A dozen Styron plastic measuring spoons are quickly formed in one piece by injection molding, then snipped apart.

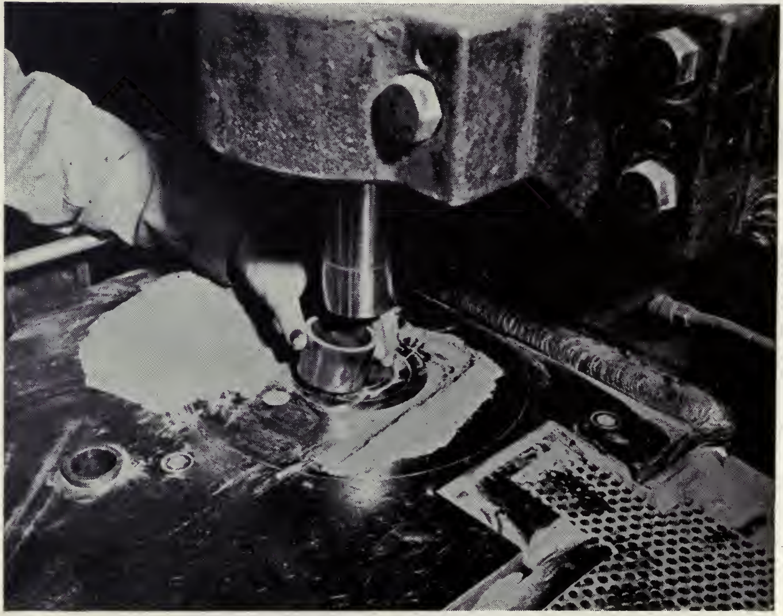


(*Courtesy Dow Chemical Company.*)

Flexible tubing of Saran plastic. Sections are joined by heating the ends and sticking them together.

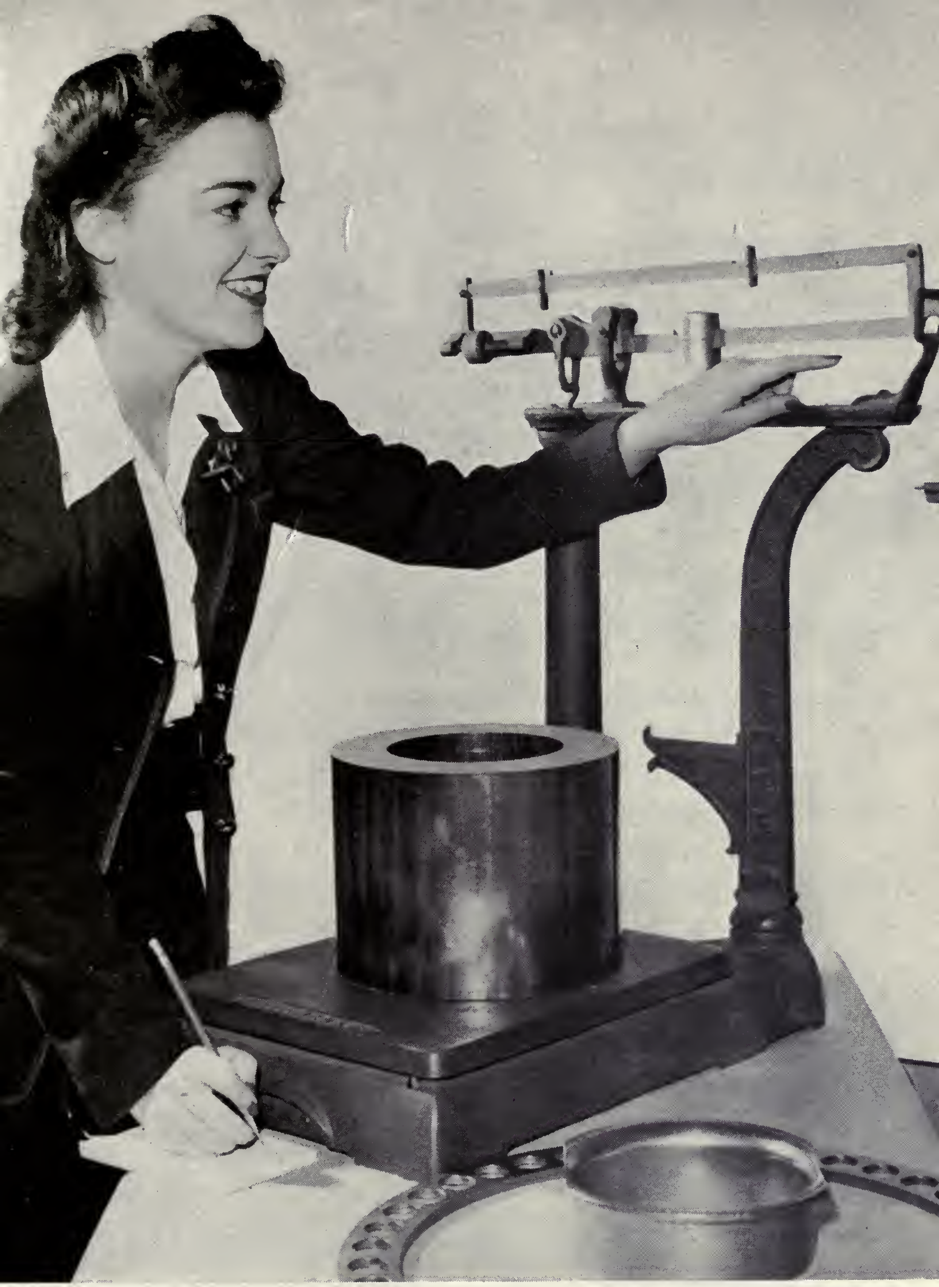
(*Courtesy U. S. Rubber Company.*)

Cabin frame of war helicopter, featherweight yet strong and durable, is made of plastic reinforced with fiberglas.



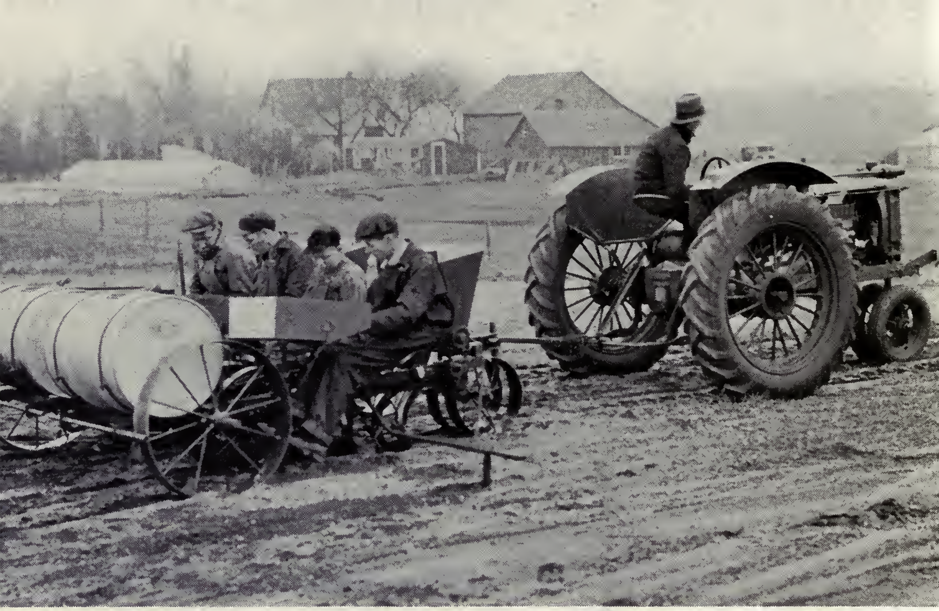
(*Courtesy Chrysler Corporation.*)

Machine parts are stamped from powdered metal like so many cookies, with great savings in time and no leftovers.



(*Courtesy Chrysler Corporation.*)

Powder so fluffy a sneeze would blow it away has been pressed and baked into a tough, 62-pound bearing for a heavy machine. Porous and soaked in oil, it lubricates itself.

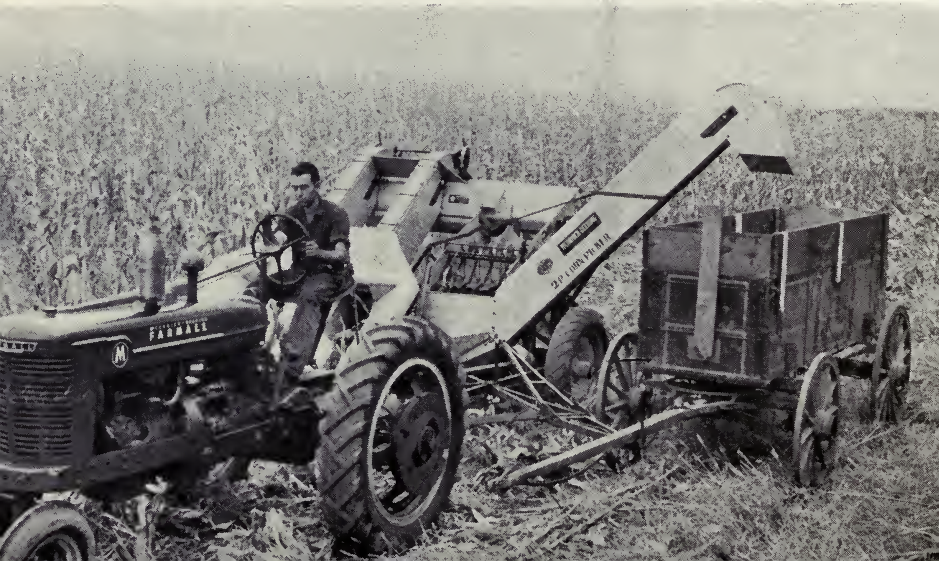


(*Courtesy Holland Celery Planter Company.*)

Truck-farm transplanting is now done semi-automatically. Men feed plants to mechanical hands which finish the job.

Driving a machine which picks and husks corn, one man does as much as many hand workers.

(*Courtesy International Harvester Company.*)



now used for taking on water and will be especially adaptable to dry areas.

Manufacturers also have their eyes on the marine power field, both naval and commercial, and a number of the new motors are being built for cargo ships and tankers. First to go into operation will be a 7,200-ton freighter for which the Elliott Company is building a seagoing gas turbine of 2,000 to 3,000 horsepower. If tests are satisfactory, the motor may be used in Liberty ships. Elimination of boilers, condensers and water-distilling apparatus would substantially increase cargo space.

Some of the advantages of the new motor in comparison with older prime movers have been summed up as follows in the *Industrial Bulletin* of Arthur D. Little, Inc.:

"The reciprocating steam engine is a complex, inefficient mechanism requiring an auxiliary steam-generator plant. The more efficient steam turbine reduces the complexity but retains the steam plant, while the gasoline engine and the Diesel, with still greater efficiency, eliminate steam but greatly increase the mechanical complexity . . . the gas turbine can outdo . . . all other prime movers in simplicity, for it eliminates the steam turbine's steam-producing and condensing system, the gasoline engine's cooling system, and the problem of lubricating hot, sliding surfaces."

Each of these features of the new motor constitutes a revolution in power all by itself, but it would be a mistake to assume that the gas turbine can be all things to all men. All machines, no matter how wonderful, have their shortcomings as well as their advantages. The gas turbine, in its present stage of development, has two outstanding limitations. First, it is a medium-size motor. It is not suited to a small job like driving an automobile, or a task like running a big electric power plant. In general suitability and efficiency, it cannot match the gasoline motor for the former use, or the steam turbine for the latter. Secondly, even in its most appropriate chores, it is less efficient than other prime movers—that is, it converts less of the heat in its fuel into useful work than does the Diesel, the steam turbine, or the gasoline motor.

All heat is theoretically convertible into power, and the most efficient "heat engine" (a phrase which covers all these motors) is the one which utilizes the greatest amount of the heat obtained in burning fuel for turning a wheel, and loses the least heat to the surrounding air. The greater the step-down in temperature between the heat of combustion and the heat of the exhaust, the more heat units there are available for work. So the hotter the gases are when they hit the turbine blades, the more powerful is their force of expansion and the more efficient is the engine.

Future possibilities

The way to greater efficiency may seem simple—regulate air intake and fuel consumption to make the gases which hit the turbine hotter and hotter. But there is a limit to the heat which turbine parts will stand. The turbosupercharger, for instance, was not a practical machine until alloys were found to make turbine blades which would operate while red-hot without losing their shape. Gas turbines now in operation at temperatures of 1,000° to 1,200° F. have efficiencies varying from sixteen per cent to twenty-two per cent, which is lower than all heat engines except the reciprocating steam engine. But with each small increase in practical operating temperatures there is a big jump in efficiency, and engineers are working on gas turbines designed to stand a temperature of 1,500 degrees and to get as much power out of the fuel as most automobile engines.

In its more complex forms, the new motor has become an elaborate system of heat-juggling, with each addition designed to cut fuel consumption and step up the yield of power. For instance, if you pipe the compressed air through the hot exhaust gases before it enters the combustion chamber you save some of the heat that otherwise would be wasted, and, by a seeming paradox, if you first cool the air on its way through the compressor, it reduces the work of the compressor because of its smaller volume, saving still more power. And there are other variations which cut the fuel bill. Engineers look forward to a day when one of these elaborate engines, equipped with a turbine that will operate at new high temperatures, will produce power as efficiently as any engine ever built.

They look forward still farther to a small, compact motor in which some gas that can take on and give off plenty of heat in a hurry will flow endlessly through a closed cycle, spinning the turbine as it expands, then going back to the compressor for more work. Any kind of fuel could be used to heat it. Among gases suggested for the cycle are argon, krypton and the Freons used in refrigeration and air conditioning. Such a motor, if it comes, might be suitable for driving an automobile.

Another possibility men are working on is a gas turbine which burns pulverized coal. They have tried to burn this fuel in a Diesel, but it scored the cylinder walls. In the turbine, it has a tendency to pit the blades. But engineers have not given it up. If they succeed in driving the simple new prime mover with this cheap and plentiful fuel, they can laugh at all efficiency figures and forget about petroleum reserves, for a new age of power will have dawned.

CHAPTER NINE

AERIAL ACROBAT—THE HELICOPTER

THE ADMIRATION of the average citizen for the Thunderbolt, the B-29, the jet plane and other darting monsters of the air is tempered with awesome respect. He has no desire whatever to sit at their controls. There is only one new flying machine which, for good or ill, gives him a conviction of adequacy and makes him feel that he, too, can fly through the air with the greatest of ease. This is the dumpy, ugly slowpoke, the helicopter, whose disarming lack of symmetry and dash helps to allay fears and breed familiarity.

The widely publicized tricks performed by this "flying windmill" complete the impression that the helicopter is a foolproof aerial kiddycar in which everyone from grandmother to the baby can gambol about with pleasure and profit. Here is an air coupé which will rise gently from the backyard, perch on a roof, hover in the air at any spot desired, turn its nose hither and yon like an inquisitive fish, nuzzle your hand like a friendly puppy, or dash off on a carefree hundred-mile trek without fear of storm or hurricane. The ground is the natural enemy of the conventional airplane, which depends upon speed to keep it in the air and a certain altitude to keep it from crashing, but the vertically descending helicopter is equally at home at an altitude of six inches or a thousand feet. In a fog, it can feel its way as cautiously as a blind man with a stick. On a holiday trip, it can pause while you speculate about a camping spot or while your wife makes up her mind about a roadside restaurant. In short, if this were the entire story, there might be justification for the common belief that tomorrow, or the day after, the helicopter will become the family conveyance, that weeds will burgeon unmolested in the highways while whirling flivvers by the million speed Americans upon their multitudinous errands.

Yes, this gaudy vision may be realized. We may also bake our bread by radio waves, heat our houses by the sun, and outlaw the common cold. In technical matters, today's pessimist stands on shakier ground than the unbridled optimist of the 'nineties. Everyone agrees that the helicopter is a fascinating invention with great possibilities, but the amateur zealots who have been trying to persuade manufacturers to accept their checks and guarantee early postwar delivery would do well to restrain themselves for a few years until the wave of perfervid publicity has subsided, and the helicopter's virtues and limitations have been fully determined by operation on a large scale.

Husky infant

Meanwhile, the helicopter has been developed so rapidly that it cannot suffer by realistic appraisal. Like the gas turbine and jet propulsion, it is both new and old. From the point of view of practical performance, the American helicopter is not yet three years of age, for it was in May, 1942, that the first Sikorsky machine was delivered under its own power to the Army at Wright Field, Dayton, Ohio, breaking all records and furnishing conclusive evidence of future worth. On this epoch-making flight, C. L. Morris, engineering test pilot for Igor Sikorsky, designer and builder of the machine, flew it 761 miles from the factory at Stratford, Connecticut, to Wright Field. The trip took five days and sixteen separate hops, averaging less than fifty miles each. Average speed was no better than fifty miles an hour. This performance recalls the trips of the first sputtering gas-buggies. Like female preaching as appraised by Samuel Johnson, it was not done well, but spectators were amazed that it was done at all. However, Morris made the machine perform a number of stunts that no fixed-wing aircraft could do. An automobile traveled the route via highway, keeping pace with the ship. Flying ahead, Morris would hover over intersections, signaling the driver when the road was clear. Approaching airports, he startled control tower operators out of their boots by stopping in the air before their windows and staring at them. When in gliding to the ground he overshot his mark on an airfield, he paused a few feet aloft and backed up to the proper spot before letting the ship down. These are only a few tricks from the helicopter's repertoire which make it suitable for many uses where the conventional airplane cannot favorably compete.

This 1942 helicopter, Sikorsky's XR-4, carried only enough fuel for a two-hour flight. In vertical ascent it could climb only about a hundred feet, then the pilot had to tilt the rotor forward and gain further altitude in the manner of an airplane. In the next two years, great things happened. It was as though a 1905 Ford were suddenly transformed into a vehicle of World War I. In March, 1944, two men climbed into Sikorsky's XR-6 at the Washington National Airport and flew nonstop 387 air miles to Patterson Field near Dayton. Breaking all records, the ship was in the air four hours and fifty-five minutes, ascended with its two-man load to 5,000 feet, and averaged eighty miles an hour.

That was the beginning of a helicopter year. Soon the Bell Aircraft Company of Buffalo, American pioneer of the jet-propelled plane, opened their doors to newsmen and unveiled a rotary-wing plane which they had been testing for months. The plane was demonstrated in an armory to show how accurately it could be controlled. An air-cooled Franklin engine, mounted vertically behind the pilot's seat, spun the two rotor blades which whirled through a horizontal circle thirty-three feet in diameter. In the tail of the craft a small vertical propeller, customary on helicopters, spun parallel with the ship, keeping the working rotor blades from pulling the cabin around with them.

For the first time in the United States, an airplane flew indoors as Test Pilot Floyd Carlson, gazing through the plastic windows of the streamlined cabin, lifted the helicopter gently from the ground and circled the auditorium, pausing at the balcony level to wave to friends, and clearing obstacles with as much control over the ship as if he had been backing a car into a garage. To show that the ship would perform as well in the open air he gave an outdoor demonstration, hovering over a designated spot on the ground while a rippling flag on a mast indicated a thirty-mile wind or better.

Not to be outdone, Sikorsky held open house at his Bridgeport, Conn., plant, subsidiary of the United Aircraft Corporation. Four helicopters staged an aerial show from what was called the world's smallest landing field, a space about 500 feet square. The ships flew as fast as 100 miles an hour, remained poised like hummingbirds at the will of the pilot, and dropped fifteen-foot rope-ladders to the ground, up which passengers climbed to the cockpit. Pilots told of flying the ships in driving snow against fifty-mile headwinds. These aircraft seat only two people, but outside the cabin on either side a closed stretcher can be attached, and this indicates a practical job for which the helicopter is already being employed.

Helicopter to the rescue

For the windmill flying machine has been coming off the production line for months for delivery to the Army, the Navy and the British Government. The full story of their military use cannot yet be told, but it is known that in Burma an Allied helicopter skimmed over the Japanese lines and picked up a wounded pilot and five soldiers who could not possibly have been rescued by a fixed-wing aircraft, which needs a field for landing. Early in 1944 the helicopter proved its worth when a U. S. destroyer exploded off Sandy Hook, New Jersey. With all regular aircraft grounded by weather, Commander Frank A. Erickson of the Coast Guard aviation unit at Floyd Bennett Field took off in a helicopter with two cases of blood plasma for survivors and landed fourteen minutes later at Sandy Hook.

The craft may also be used for rescue work at sea. A helicopter can hover over a life raft, lower a ladder or body harness, and pull up stranded pilots or seamen in rough weather without risking descent to the surface. By settling perpendicularly to the ground in a secluded spot, it could land special agents and equipment behind enemy lines without the hazards of parachuting. The Navy has conducted tests in which helicopters used space on ships' decks as landing fields, and Liberty ships have been redesigned to provide for helicopter platforms. This craft may be used for the protection of convoys against submarines. When it sights an undersea boat, it can hover directly above it and drop a depth bomb with an accuracy impossible to a conventional plane. It would seem to be ideal for liaison work in field maneuvers, where the demand is not for fast planes, but for planes so slow that officers can follow the movements of troops. It has been the boast of some manufacturers of small sports planes that their craft will almost stand still. In a helicopter, an officer can take up a stationary position aloft for as long as he wishes, criticizing troop movements or correcting artillery fire by radio. These are only a few of the jobs which may or may not be done today by the helicopters of unknown number now serving in the war.

Da Vinci thought of it

We have said that the helicopter is both old and new. It is as old as Leonardo da Vinci, the remarkable fifteenth-century genius who thought of almost everything. It is believed that da Vinci built model helicopters that flew, and it is certain that he left sketches behind him showing his interest in the helicopter principle. It was inevitable that those who wished to emulate the flight of the bird should think of wings that flapped, and that after weighing the mechanical difficulties of such direct imitation, they should hit upon the idea of birdlike wings which by rotating provided buoyancy and forward propulsion. An endless procession of woodshed Icarus Greens tried to build helicopters, many of them incorporating foot-pedal arrangements in their designs by which the operator was supposed to whirl the lifting rotors by his own muscular power. But man was not engineered for such personal adventures. Someone has figured out that a correctly designed angel would have an indelicately gargantuan chest development and weight-saving claws instead of legs, and it would seem that the habitual operator of a pedaled helicopter would have to be conversely configurated. Generations of breeding might achieve this end, but while we have motors and fuels such a project would be too undignified and uneconomic. Yet as recently as 1938, W. F. Gerhardt, who had once pedaled in the air for a short distance in a tiny fixed-wing airplane, built a man-powered helicopter at Wayne University, Detroit, and the wife of a faculty member managed to get it off the ground.

Many distinguished names occur in the list of early experimenters with the helicopter idea, among them Hiram Maxim, Thomas Edison, Peter Cooper Hewitt, Emile Berliner, inventor of the microphone, and his son Henry. In 1907 Breguet of France built a machine with four lifting rotors, in which he flew a distance of sixty-four feet. But the practical development of rotary-wing aircraft did not begin until after World War I, and then it was the autogiro, not the helicopter, which took the lead.

Like the helicopter, the autogiro has an upright metal post, extending from the cabin, which is the axle of long revolving blades. But in flight these blades are not driven by the motor—they rotate freely as the airstream strikes them, and serve the same purpose as the airplane's fixed wings by providing "lift" to keep the craft in the air. The craft is driven by an ordinary aircraft engine which rotates a propeller in the nose like that of a conventional plane, but in recent designs there is an arrangement for hooking up the engine with the overhead rotor to give the craft a jump start, lifting it a few feet off the ground, after which the conventional propeller takes over and the rotor rotates in the airstream like a free windmill. The angle at which the rotor blades bite the air can be regulated. When the pilot wishes to take off, he spins the rotor by engine power with the blades almost parallel to the ground. After they have reached sufficient speed, he suddenly changes their angle, they bite into the air, and up he goes.

The autogiro shares some of the advantages of the helicopter. The pilot can shut off the power and descend vertically to land on a space of pocket-handkerchief dimensions, and he can fly very slowly without fear of stalling. But this craft lacks the amazing maneuverability of the helicopter. Because of its conventional propeller, it can go only forward in ordinary flight, and it cannot, without the assistance of wind, hover over a spot on the ground.

Autogiro pioneer

Several inventors built experimental autogiros after the close of World War I. A Spaniard, Juan de la Cierva, is given credit for the first successful one. De la Cierva had been experimenting with aircraft for years. Disturbed by the many fatal accidents caused by stalling, he brought out his autogiro in 1919 as a safer type of aircraft. It contained a device which was destined to have a profound influence on all rotary-wing ships. It is obvious that as a "windmill" ship goes forward, the rotating blade gives more lift on the side which is moving against the wind than it does in the other half of its orbit where it is moving with the wind. De la Cierva corrected this by making the blades flexible so that they altered their pitch with each half-revolution, thus balancing the ship and giving equal lift on each side. This principle is now used on many helicopters.

No popular conception of rotary-wing flight is complete without a roof landing field on an apartment house or office building. Unlike some notions of the coming age of flight, this one is perfectly sound, and has been proved not only by test but by a long period of daily scheduled operation. In 1935, two different autogiros winged their way over the Philadelphia suburbs and nestled down on the roof of the Post Office, bearing sacks of mail. This demonstration was so impressive that in 1939 the Department awarded a contract to Eastern Air Lines for daily autogiro mail delivery from the Post Office roof to the Camden, New Jersey, airport six miles away. Service began without incident in July. The roof was not ideal for the purpose. It provided a landing field about 350 by 250 feet, but structures on either side made it a canyon, and there was danger that in landing a sudden gust of wind might blow the craft into the side of a building. Yet the pilot, Captain John M. Miller, took off each day with humdrum regularity. By applying the engine power to the rotor he made a "jump start" a few feet in the air, then by means of his propeller got entirely clear in about 250 feet. After a time his destination was changed to the new Philadelphia airport, also six miles distant. The service was continued for a year, and if it cannot be said that nothing stayed this modern courier from the swift completion of his appointed rounds, at least he completed ninety per cent of all scheduled flights. The service was abandoned after a year, not because it was considered a failure, but because the experiment had been shown to be a complete success. The Post Office Department had proved the usefulness of the plan, and shelved it until such time as funds should be available for wider use.

No helicopters were ready for service in 1939, but today's powered-rotor ships would be safer and more efficient for taking off and landing on roof-tops. They would need less space, and would be less sensitive to surrounding projections and drafts of air. They would, of course, rise vertically until they cleared all obstacles. But if roof airports become common, architects will pay particular attention to all factors having a bearing upon safety, and it may be that penthouses sheltering air-conditioning and other equipment will be designed and located to suit the needs of helicopter traffic. One plan suggested, which may or may not turn out to be sound, is a roof garage topped by a horizontal sliding door. Travelers would take the elevator to the garage and seat themselves in the aerial bus, then an attendant would zip the roof back and the helicopter would take off like a pigeon from a cote.

People who raved about the autogiro were soon to transfer their enthusiasm to the helicopter. In 1938, in the Deutschlander Halle, a large auditorium in Berlin, the first reliable ship with an engine-driven rotor was put through its paces before an admiring audience. This was the helicopter of Dr. Heinrich Focke. Like the Bell machine in Buffalo last year, it rose easily from the floor and was deftly piloted around the room, settling again to the floor as softly as a falling leaf.

Enter Sikorsky

Igor Sikorsky, the noted aircraft designer who created the clipper transport plane, followed fast on Focke's heels with his first successful machine. He had begun experimenting with the novel craft in Russia, and in 1909 and 1910 had built experimental helicopters with two rotors. His second ship rose from the ground by itself, but would not support the weight of a pilot. It was an education rather than an achievement. In intervals between his brilliant work on conventional airplanes, Sikorsky pursued his rotary-wing goal, and thirty years after his first attempt, he had completed a practical helicopter. In 1940 he took the ship off the ground and stayed in the air for fifteen minutes; the following year he kept the craft in the air for an hour and a half—a world endurance record, and then in May, 1942, occurred the flight of many hops to Wright Field, an achievement followed by more Army orders and public realization that another of man's pretentious dreams had come true.

While the whirling skycraft of Sikorsky and Bell have received widest attention, helicopters of other types are being manufactured or are in the process of gestation. In the early twenties, the late Dr.

George de Bothezat, working with the Army Air Corps, built a helicopter driven by four rotors, which stayed in the air briefly on a number of test flights. This model was rather cumbersome and was abandoned, but the Helicopter Corporation of America is now making a simpler and more efficient flying machine designed by de Bothezat. This helicopter has two rotors mounted on the same vertical mast, rotating in opposite directions. Since the contra-rotating rotors cancel the tendency seen in other models to pull the ship around, there is no need of a small rotor at the rear to keep the craft pointed straight. To steer this helicopter, the pilot simply changes the pitch of the blades in, for instance, the rotor which spins clockwise, so that it offers less resistance to the airstream and allows the counter-clockwise rotor to change the forward direction of the ship. And to steer the ship in any horizontal direction, the whole propulsion unit, engine, rotors and all, are tilted in that direction. The inventor had tremendous enthusiasm for the craft's future. He foresaw giant machines carrying many passengers, and he also planned a light and simple one-man craft which should sell at a low price and will fascinate the adventurous if it is ever displayed in a shop window.

Another machine with contra-rotating props, called the "Hillercopter" by its nineteen-year-old inventor, Stanley Hiller, Jr., was successfully demonstrated in San Francisco last year. Hiller has designed a new and secret mechanism which controls the pitch and speed of either or both of the two rotors. He has been commissioned by the Navy to build a larger machine on the same lines.

Another entry in the field is sponsored by Higgins Industries, which has been testing a helicopter designed by Enea Bossi with a view to large-scale postwar production. Only a few years ago, Bossi, an aeronautical designer of long experience, built a tiny man-powered plane and succeeded in getting it off the ground; now his restless, contriving mind has spawned another unusual craft. Above his two-seater cabin there is a rotor with four blades, one pair set above the other but all turning in the same direction. This rotor has a universal mounting so that no matter how it is inclined in flight, the cabin remains horizontal. It has a tail propeller which keeps the ship from turning sidewise, and also acts as a rudder. The inventor claims that the ship is so stable that the pilot can take his hands off the controls without risk. It has a 175-horsepower air-cooled motor, and is said to fly at the same speed as a conventional plane with the same power plant. Another wartime industrial titan, Henry J. Kaiser, has mounted the helicopter bandwagon, and is grooming a craft of new design at his Fleetwings Division.

There is also the sturdy-looking Platt-LePage helicopter, which appears from the front to have stubby airplane wings. These side extensions are really tubular supports for the ship's two rotors. Since the rotors turn in opposite directions, there is no "torque," or tendency to rotate the craft itself, so no tail rotor is needed to insure straight flight.

Late in 1943, a single-seater machine produced by P-V Engineering Forum, Inc., of Philadelphia, took to the air in Washington and performed the unique stunts of the helicopter. Like the Bell craft, it is driven by an air-cooled Franklin engine, a motor which may be in great demand if the whirling-wing program lives up to expectations. The P-V craft has a gross weight of a thousand pounds and a top speed of ninety to 100 miles an hour. Each of these new ships has mechanical features which its makers believe make it superior to its rivals, and new ideas are constantly germinating.

At the time of writing, twenty-five firms and organizations are either actively building helicopters or planning to build them, and at least fifty firms are making or preparing to make component parts for them. The flying machine which at the time of Pearl Harbor hardly existed as a practical device is now backed by the best money and brains in the country. But its warmest friends insist that it is still in its infancy, and are seriously afraid that its prospects may be ruined by a wave of unbuttoned public enthusiasm inspired by grandiose publicity.

"Let's be calm"

Lou Leavitt, former test pilot and now consultant to rotary-wing aircraft manufacturers, has written in *Aviation* under the title "Let's Be Calm About the Helicopter":

"Advent of the helicopter has been heralded with a torrent of publicity—a torrent which is fast threatening to become as destructive as that which first awakened public enthusiasm for the autogiro. Why a basically new type of aircraft which has not yet wholly convinced the airmen and engineers who make their living at aviation should immediately be vaunted as the answer to a housewife's prayer is not very understandable unless it be explained by the American flare for all-out enthusiasm in a new cause."

The autogiro was retarded, writes Mr. Leavitt, by sweeping claims that it was a foolproof craft which could "take care of itself and the man who flies it."

"It never became a finished product largely because the American public never let it become one. The . . . publicity which swept the country also swept the few closely owned, patent-holding companies with the result that the autogiro was literally tossed into the hands of enthusiasts who lacked even the ability to ride a bicycle.

"Already we have seen articles about housewives flitting merrily about the sky . . . with pictures of them gassing up at the local filling station. We are told it is the 'flivver' of the future . . . And, judging by the number of rotary-wing experts that have suddenly popped up all over the country, the need for a wailing-wall is going to be terrific in a very few years."

It is true that the helicopter is more maneuverable than any other aircraft. It will stand still, it will back up, it will crawl at snail's pace, it will dash forward at 100 miles an hour, it will go up, down, or sidewise or perform various combinations of these movements—in the hands of a skilled pilot. But as Col. H. F. Gregory, Army rotary-wing authority, has pointed out, this rich variety of possible movements makes the ship much more difficult to control than the conventional plane. Last year Col. Gregory stated that the Army had less than twenty qualified helicopter pilots, and these men were all experienced airmen before they took lessons on the new craft. The helicopter pilot must master about as many coordinated movement patterns as a pipe-organ player, and in a two-seater craft, if he changes places with his partner he must use his left hand for motions he formerly did with his right, and vice versa. Of course we are dealing with the ship in its present state. The helicopter of the future may be outfitted with a mechanical brain, but until that time comes, the skies will not be black with commuters bound for city rooftops, or housewives on shopping tours.

Much has been written about the backyard helicopter landing field, but this would not be practical in most backyards. The powerful downward gale from the whirling blades would blow dust and leaves through doors and windows, and wives would scuttle for cover instead of gaily bidding farewell to their helicoptering mates as they do in pretty pictures of the future.

Another notion which tickles the imagination is a helicopter that will fold its wings and take to the highway like an automobile, and mechanical composers have also written scores for such bi-functional airplanes. This is not impossible as a stunt, just as a poultryman might conceivably breed a turkey that would fly like an obese and arthritic eagle. The engineering requirements of land and air locomotion are contradictory, and unless someone passes a miracle it is the part of wisdom to read about such fascinating gadgets instead of buying one.

As for safety, it is well known that if the helicopter's motor dies at a good altitude there is little danger of a crash, for the blades of the rotor, turning freely, will ease the descent, but Col. Gregory states that there is an altitude danger zone between thirty and 300 feet. If the engine fails in that altitude zone, the occupants may be in for a hard and possibly fatal crash.

These are some of the limitations of the helicopter *in its present state of development.* In view of the progress of the airplane since Kitty Hawk, it will be remarkable indeed if this three-year-old flying machine is not vastly improved in the next decade. These limitations mean simply that any aircraft is an aircraft, and that one has to be a qualified aviator to fly one.

Once we dismiss the nonsense, we can get a clear view of the many potential uses of the new craft. Especially impressive are the plans to use helicopter busses on "feeder lines" to supplement the big air-transport systems.

Aerial busses to come?

The Greyhound Corporation, whose bus routes extend over 63,000 miles of highway, has applied to the Civil Aeronautics Board for authority to operate helicopters over routes totalling some 50,000 miles. Greyhound's purpose is to coordinate air service with bus service, as well as to furnish "feeder" air service to many towns where passenger traffic is too light to support commercial airplane service. Just as the bus has become indispensable in serving communities which cannot support rail transportation, the helicopter would tie up the small towns with the big airfields. Existing bus stations would be enlarged to provide for helicopter take-off spaces and garages, and present waiting rooms, repair shops and other facilities would serve both ground and aerial busses. According to Greyhound's figures, air transportation is now conveniently accessible to 37,000,000 of the country's population who live in 160 cities. The company proposes to bring convenient air travel to an additional 70,000,000 people, and is of the opinion that the fares in such a helicopter bus service would be no higher than the cost of private automobile travel.

If this plan comes to fruition, we may envision tomorrow's summer-jaded New Yorker boarding a helicopter at a centrally located bus station, and traveling in cool, dustless comfort to a town in the Vermont hills. Or he might "helicop" to LaGuardia Field, board a plane for Montreal and change for a flying bus to the Laurentians.

Greyhound also points out that in many present air trips of 250 miles and less, a disproportionate amount of time is spent in going to and from air fields. In going from Chicago to Detroit, the air traveler spends fifty per cent of the time on the ground, and sixty-two per cent of the time is spent in ground travel in an air trip from New York to Philadelphia. Helicopters taking off from the center of a city would extend air travel by making shorter flights worth while.

So far as is known, no helicopter now exists which will carry more than two people, but designers have complete confidence that much larger ones can be built. Sikorsky stated at the CAB hearing that it would be entirely practical within the immediate future to build a transport helicopter which would carry two crew members, fourteen passengers and 400 pounds of cargo. Such a craft, he estimated, would need 1,200 horsepower, supplied either by a single motor or a group of smaller ones, and at a cruising speed of 100 miles an hour, would need about 100 gallons or 600 pounds of fuel to carry it 150 miles. Sikorsky is not alone in his anticipations. Vincent Bendix, who recently announced the formation of Bendix Helicopter, Inc., is working on plans for a ten-passenger one-ton helicopter of 600 horsepower and a twenty-passenger two-ton air bus of 1,200 horsepower.

The date of arrival of these craft depends on the war's duration. Much of engineering work now being done on military helicopters is directly applicable to the production of a rotary-wing air bus, states Mr. Sikorsky. It is well to reiterate that the practical helicopter is so new that the gloss is still on it. Scores of modifications and revolutionary changes are being considered. One of the most arresting of these ideas is a novel use of the newly developed gas turbine to drive the craft. The rotor blades would be hollow and the expanding gases from the motor would flow through them, escaping through jets at the curved tips and rotating them, just as water flowing through a garden hose rotates the arms of a familiar type of lawn sprinkler. Such a motor, now used in a different form to drive jet-propelled planes, would be light and compact, and the power would be directly applied.

Whatever form the helicopter may take, it is definitely emerging as a new factor in locomotion. It may be that its first important uses will depend upon its unique ability to stand still in the air. This special advantage may make it invaluable for spraying crops and orchards, for spotting crop and forest infestations and for directing control of forest fires. It may also be used for patrol of pipe lines, direction of highway traffic, locating and herding live stock on large ranches, relief and rescue of flood victims, wire laying, stocking streams with fish, geological surveys and peacetime aerial mapping. The drama of its development will attract a full house, and the curtain will rise as soon as our enemies bite the dust.

CHAPTER TEN

POWER FOR TOMORROW

As war demands slacken and the tools and gadgets of peace once more stream from the factories, millions of American families will rush to gratify their greatest deferred desire—the purchase of a new automobile. Other millions will buy busses, trucks, tractors, motorcycles, outboard motors, auxiliaries for yachts, stationary engines, both gasoline and Diesel, and home furnaces that burn oil. And aircraft of all kinds—gluttons for fuel, since they use it both for propulsion and to overcome gravity—will multiply. We may also expect an increase in the demand for packaged petroleum gases for household cooking and heating and for industrial uses. There is the demand, new since Pearl Harbor, for petroleum products to make artificial rubber, and in lesser volume, increased use of the plastics and other chemical products which are fashioned from crude oil.

Judging by historical trends in American consumption, there will be no interruption to the prodigious and constantly increasing demand for energy in the production of power, heat and light. The National Resources Committee estimated in 1939 that our per capita consumption of energy was fifty per cent higher than that of Great Britain, more than twice that of Germany, more than ten times that of Japan, and 150 times that of China. The report stated that in 1937 the total of energy used in the United States—for purposes all the way from electric-power generation to running the family car—represented for each family in the country an equivalent of 120 horsepower, eight hours a day, six days a week, and that over a period of forty years the total amount of energy used annually increased 600 per cent. No reliable estimates are available for the boom war period, but we may draw conclusions from the fact that production of electric power has increased by one-third since the United States entered the war, and that production of gasoline and Diesel oil is straining the capacity of refineries.

Power is obtained from a number of sources, but the most convenient way to produce it is by burning irreplaceable deposits of coal, gas and oil stored beneath the crust of the earth. In petroleum, Nature has provided a packaged power source most available to man, and man, to whom the easy thing always seems the most efficient, has taken full advantage of the fact. Soon he will be scraping the bottom of the barrel.

Since Colonel Edwin L. Drake tapped the first American oil well in Pennsylvania in 1859 we have consumed 27,000,000,000 barrels of the odorous "black gold." And we have wasted uncounted billions of barrels in the process. At first we used only the kerosene, and killed the fish in rivers by dumping in them the then useless gasoline. Oil producers have wasted tremendous riches in natural gas, by burning it or allowing it to escape into the atmosphere.

"In twelve years in California," reports the National Resources Committee, "the quantity of gas known to have been wasted was about one-third of that produced for commercial use, and in 1929-30, the heating value of gas wasted from the Kettleman Hills field was equivalent to the expected energy output at Boulder Dam during a like period." There are similar reports of waste in Texas, Oklahoma and elsewhere. In blithely tossing away an empire of energy contained in the wasted gas itself, we have also thrown away a priceless tool for the production of petroleum. Oil is driven from the ground by gas pressure, and when the pressure is gone, great subterranean reservoirs remain forever unobtainable. In addition, many wells have been abandoned because of fluctuating prices, leaving great residues of oil which have been lost forever.

There have been similar inefficiencies in distribution. As producer of sixty per cent of the world's petroleum, we have exported great quantities of oil which we should have left in the ground to provide for military emergencies and to delay the day when we will be dependent upon imports to fill our peacetime needs. We have used this admirable source of power for heating houses, when coal is cheaper and we have plenty of it. In short, we have made the proverbial drunken sailor look like a Caspar Milquetoast.

So in the last eighty-six years we have used 27,000,000,000 barrels of petroleum. We have thrown away or misplaced many more billion barrels—and we have only 20,000,000,000 barrels left that we know about. We are now using this reserve at the rate of about one and six-tenths billion barrels per annum, for we are furnishing eighty-nine per cent of the oil used by the Allies to fight the war. But we cannot blame the war for this alarming depletion of our petroleum principal, for even in the years before Pearl Harbor and Lend-Lease we were using about a billion and a quarter barrels every year, and consumption would have proceeded at least as rapidly had there been no war.

Since everyone wants to ride in his postwar car, and in the new planes and helicopters, there is little expectation that demand will fall off after the war sharply enough to make any great difference in the prospects, so, if you take paper and pencil, you may conclude that we will have oil enough at the present rate of consumption to last twelve to fifteen years. But there is a flaw in this figuring. We cannot get that 20,000,000,000 barrels whenever we want it. As wells grow older, their rate of flow slows down, and hasty production is often wasteful production. So it may take at least seventy-five years to get the rest of our oil out of the ground. There are, of course, more oil fields to be discovered. Dr. Kirtley Mather, Harvard geologist, has stated that our unknown reserves may run to another 20,000,000,000 barrels. But we have skimmed off the cream, and new deposits are harder to find. New discoveries have been running behind consumption for the last eight years, and recently we have not even been finding new oil enough to equal rationed civilian consumption.

In a country which regards automobile travel as an inherent right, this situation is to be deplored, but in the immortal words of Petroleum Administrator Harold L. Ickes: "As you go vociferously forth draped in the outer garments of patriotism and the underwear of self-interest, please remember that our tanks and trucks and jeeps cannot burn as fuel the crocodile tears that you shed."

Statisticians with slide rules are working day and night on this problem, and their estimates vary. But it is reasonable to expect that soon after the war the United States, unable to meet its oil requirements, will make up the deficit by importing oil from the Caribbean area, that in X years she will be forced to go farther afield for petroleum, and that in Y years the world's petroleum will be exhausted or will be prohibitively expensive to obtain. In any event, it is not too early to start doing something about it. And there is plenty that can be done. We need not be bound to petroleum. We may be forced to make uncomfortable changes in our habits, but as long as sunshine and gravity last, there will always be sources of power to run our machines.

The three atoms

The perpetual cycle of the earth's fuel supply is a sort of endless dance for three partners—carbon, hydrogen and oxygen—which are confined forever to the earth and its atmosphere by gravity. And the sun, source of all energy, calls the turns. Driven by radiant solar energy, these three atoms are snatched from their free flight through the atmosphere and forced into various molecular combinations known as carbohydrates, which are the building blocks of all vegetable matter. Here, precisely ordered and proportioned, they carry with them a bit of solar energy now incorporated into the inner bonds which hold them in chemical combination.

When the plants have died and become a part of the earth's crust, these carbohydrate compounds undergo vast and protracted changes in their inner arrangements, which, after time-periods too long to comprehend, convert them into the world's familiar fuels. Some of these carbohydrates are eaten by animals and fish, whose bodies, embedded in the plant debris, also contribute to the end product. During the process of conversion, the buried matter loses most of its oxygen, and the residue, composed mainly of carbon and hydrogen, takes the permanent chemical structure of a hydrocarbon. Petroleum is a mixture of assorted hydrocarbons, and so is natural gas. In coal, even the hydrogen is partly driven off, and the remainder is largely pure carbon. During all these conversions, the captured solar energy is retained in the molecules, and to use this energy we must combine oxygen with the carbon and hydrogen in the process called combustion.

Petroleum, natural gas, shale oil, asphalt, anthracite and bituminous coal, and cannel coal all represent different stages in the slow conversion of plant carbohydrates into the hydrocarbons which we burn.

Whatever their form, man seizes them and feeds them into furnaces, stoves, fireplaces, engines, lamps and dozens of other devices designed to utilize the bottled-up bit of solar energy which long ago dragged the three partners into the carbohydrate formation. Thus released from their bonds, the atoms once more leap freely into the atmosphere to await the call of the sun to begin another round. Bound to the earth by gravity and driven into ranks by the fury of the sun, there is no escape for the fuel-making trio. And this is one of the keystone facts of human existence.

The form in which the fuel is made available to man, and the efforts he must make to obtain and utilize this fuel may change with time. But some kind of fuel will always be there. Just now we are consuming fuel supplies which largely began as carbohydrates in the Carboniferous period, 100,000,000 years or so ago in the geologic time scale. Of these forms, petroleum offers least resistance to exploiters. A few skilled, hard-working men can drill down through the overlying layers of rock to reach and release enough crude oil to supply the wants of millions. Once the wells are drilled, it takes a minimum of maintenance and operating labor to keep them pouring forth their liquid fuel until the pool beneath is exhausted. On the other hand, the solid fuels must be arduously chopped and blasted, and carried, bit by bit, to the surface. Moreover, petroleum and its various liquid and gaseous derivatives are much easier to distribute and consume than solid fuels. They will flow through pipes, they do not scratch metal parts, and they do not disintegrate into wasteful and annoying dust. So man, as usual, has been eating his white bread first.

There have been dire prophecies of a black day to come when word will flash from coast to coast that the gasoline is all gone. Patients dying because the doctor can't get there, riot and pillage because police cars are immobilized, starvation because produce trucks are impotent, and so on. This is a dramatic way of putting things, and perhaps any scare story that will jar a spendthrift nation is justified, but the inevitable exhaustion of petroleum will not take place suddenly. No Paul Revere galloped to the clipper ship docks shouting "Steam is coming!" There will be a chance to adjust our machine civilization to dry oil wells if we have the sense to use the time remaining. We must recall that petroleum formed itself beneath the ground with no idea whatever that a certain egocentric mammal might find it of value, that if there were no petroleum, we would have made out with something else. When oil barrels run low, our powerful desire for survival will prompt us to find a substitute, which we will probably label an "improvement."

We will turn to other forms of fuel in the earth. From these alternative sources of stored energy we will make aviation gasoline, kerosene, lubricating oil and all the other fluids now produced in oil refineries. After the adjustment period, we will get along about as well. The manufacturing methods will be a little more exacting than those now applied to petroleum, but the end products will be equally satisfactory. And after even the stored energy is gone, we may employ "quick aging" methods (now partially worked out) to accomplish in a few hours what was done in the entrails of the earth since the Carboniferous days. And at some point in the great procession of improvisations, we may learn to take power directly from the sun's rays without the employment of plants as middlemen.

Fuel from tar sands

The conversion of non-petroleum stored energy into liquid fuels is a relatively simple chore. The carbon sources we will employ are tar, shale oil, coal and natural gas. Consider first the tar supplies. In Northern Alberta in the watershed of the Athabasca River lie 10,000 or more square miles containing deposits of sand saturated with the thick, asphaltic oil. Coming up from the depths to reach the surface at a few points, these vast stretches of tar-soaked sand contain enough imprisoned solar energy to supply North America for perhaps 100 years with the fuel now extracted annually from petroleum. However, in order to obtain the tar for subsequent refining, the tar-sand mixture must be extracted from the ground by mining methods. The tar, unfortunately, will not flow up to the surface under its own power when a well is drilled down to its resting place. And once brought to the surface, it must be washed away from the sand with hot water before refining operations can begin.

Shale oil awaits

A second source of stored sunshine are the shale-oil deposits, which are spread across the face of the entire globe. Colorado and neighboring states have tremendous reservoirs of oil shale. These beds of finely stratified, clay-like rock contain layers of long-decomposed plant matter, and when the rocks are crushed and heated, liquids resembling crude petroleum ooze out. Oil has been commercially extracted from shale for many years in places far from petroleum fields. Small shale-oil deposits have been worked in Scotland for ninety years, and Australia has experienced a wartime shale-oil boom. New South Wales now produces 4,000,000 gallons of gasoline per year from shale oil and expects to increase this output sixfold in the near future. Like the tar-sand fuel, gasoline from shale oil costs more to produce, but it is abundantly clear that shale oil can replace petroleum whenever and wherever it is needed.

Gasoline from coal

The description of these tar and shale-oil reserves sounds impressive, but they represent only a fraction of the total solar energy stored up in the Carboniferous period. The world's coal deposits, under the skillful manipulations of chemists and engineers, can be made to yield liquid fuels for planes, cars and furnaces.

Were it not for this fact, the German war machine would have run down long ago, and it is even possible that without synthetic gasoline from coal the Nazis would have been in no position to start the war. Dr. Friedrich Bergius, distinguished chemist and Nobel Prize winner, made a discovery in 1913 which went far to liberate his country from the domination of petroleum imports. In experiments to determine what chemical changes could be brought about by high pressure and heat, he found a way to force hydrogen gas into the carbon of coal, and the result was a liquid hydrocarbon similar to crude oil. In the middle twenties, the giant German chemical corporation, I. G. Farbenindustrie, put Dr. Bergius' plan into commercial production. Powdered coal and hydrogen, subjected to terrific pressures, change to a kind of "crude," which is then refined to yield gasoline and oil. Petroleum Administrator Ickes has estimated that Germany may have been making as much as 50,000,000 gallons of gasoline annually by this method.

The widely discussed Fischer-Tropsch process is another pillar of Axis fuel production. About thirty years ago, the Kaiser Wilhelm Institut für Kohlenforschung was placed under the direction of the then-young Franz Fischer. Fischer began an intensive study of the properties and composition of coal and the gases which could be made from it. Fischer and his co-workers, principally Tropsch, perfected processes which employed as a starting material a mixture of the gases, carbon monoxide and hydrogen. These gases were readily made from coal in a manner similar to that used in most metropolitan "gas works." The mixed gases were then passed through catalyst chambers which caused the carbon, hydrogen and oxygen (the basic fuel-making trio) to combine into petroleum-like liquids. By employing various catalysts and by subjecting the liquid products to operations similar to those employed in petroleum refineries, the Fischer-Tropsch synthesis evolved an astonishing variety of vital materials. Out came high-octane gasoline, premium-grade Diesel fuel, first-class lubricating oils and waxes essential in making many types of electric insulation.

The New Order was quick to recognize this research. Within two years after the Reichstag fire, the Ruhrchemie A.G. had placed in operation a large commercial plant for making synthetic gasoline from coal by this new method, which is another major factor in keeping the German war machine going.

Aware at last of the handwriting on the wall, the United States is now building experimental plants to make synthetic oil as a hedge against the inevitable future shortage of natural petroleum. Dr. H. H. Storch of the Bureau of Mines laboratories at Pittsburgh has played an important part in calling attention to the need for such plants. Near his office is a small pilot plant for converting coal into gasoline by adding hydrogen atoms to the carbon molecules as Bergius did. Coal goes in, and good quality motor fuel trickles out. When a delegation of

Congressmen, concerned about our oil supply, visited the laboratory, they rode away in cars driven by Dr. Storch's home-made gasoline. Now Congress has passed a bill authorizing the Bureau to spend $30,000,000 constructing more demonstration plants. This is a triple project for making gasoline from shale oil, by the Bergius direct hydrogenation process, and by the indirect Fischer-Tropsch method, in which gas is made from coal, and motor fuel from the gas.

The processes which convert coal into gasoline may also be used, with a few modifications, to make airplane and automobile fuel from natural gas, and whenever scarcity pushes the cost of American petroleum high enough to warrant the commercial production of synthetic fuel, gasoline made in easy fashion from natural gas will receive first consideration, in the opinion of able petroleum engineers. But it is not likely that any large part of our gasoline will be made in this manner. Natural gas, once wasted into the sky but now carefully conserved, by law, is in great demand as a household fuel. It is an essential raw material for making the carbon black which reinforces automobile tires. And even at the present rate of consumption, our natural gas reserves are good for only about thirty years.

Power from bottled gas

Many kinds of gas are used for power. For years, busses, trucks and tractors on the Pacific Coast have been driven by propane and butane gases carried in cylindrical tanks, and manufacturers have adapted farm vehicles to its use. These gases, identical with the trade-named gaseous fuels which are delivered in cylinders for country cooking ranges, are liquid under pressure, and expand when released in the cylinder head. Dr. Gustaf Egloff, noted petroleum authority, reports that 25,000 West Coast motors are being driven by these gases. Two hundred busses in the state of Washington are driven by liquefied gas, and the entire bus system of Spokane uses the fuel. Engines require some adjustment to burn the gas, and it will not yield the miles per gallon of gasoline or perform as well on hills. Yet it has become so popular during the war that the government has had to tighten restrictions on its use. For butane is the raw material for butylene, which yields components for aviation gasoline and synthetic rubber. Once it was a wasted by-product of petroleum refining, but it is now in such demand that it is not likely to fill the role of our dwindling petroleum.

There is, however, an unrationed source of gaseous fuel—sewage. Methane gas made from city sewage and other starting materials has been used extensively in Europe to drive vehicles. In Zurich a fleet of forty garbage trucks is driven by methane gas made in the city sewage plant. A trailer-bus to an amusement park near Springfield, Mass., has been allowed to maintain its "non-essential" schedule because it operates on a gaseous fuel partly derived from sewage.

Acetylene, hydrogen and ammonia gases are also listed by Dr. Egloff as substitute motor fuels. The combustible gases used in Europe, he states, are estimated to have replaced 3,000,000,000 barrels of gasoline in 1943, and at latest reports, about a quarter of Germany's commercial vehicles were running on gas. Many are run on charcoal, wood or other fuel which is burned in the vehicle itself. Today, these fuels are rightly regarded as makeshifts, and they would find little use if gasoline were plentiful and cheap. They represent, however, another reason why cobwebs need not accumulate on steering wheels, and like other alternative sources of power, they are susceptible to improvement.

As the store of natural petroleum and natural gas continues to decline, we will turn to the large-scale exploitation of the tar sands and shale oils. It seems likely that these will receive attention before we embark on large coal hydrogenation projects. Comparative cost will, of course, play an all-important part in determining the progressive steps from one source of power to another. Gasoline now made in England by coal hydrogenation under government subsidization costs several times the refinery price of American gasoline, but this is no guide to the future. No one can say that our chemists, armed with experience gained from new refining methods, will not sometime make gasoline from coal just as cheaply as it is now made from petroleum.

Meanwhile, our natural petroleum assets should be preserved and "stretched" with the greatest care, because petroleum, while it lasts, is supreme in the field of mobile power. Burning it to heat houses is a stupid waste of potential horsepower and should be stopped. And long before dry wells send petroleum prices soaring, the synthetic processes should be thoroughly developed, by government subsidy if necessary, and prepared to take over the great power job. Then we will enter upon a period, lasting a century or more, in which we will consume our nonliquid supplies of stored energy.

Power from powdered coal

This suggested schedule of the future of power is subject to change without notice. Engineers are working on fascinating possibilities which may suddenly invalidate all estimates and time tables. Among these is the plan of burning finely powdered coal, instead of a liquid fuel, directly in the internal combustion engine—a proposal we have already mentioned in connection with the Diesel engine and the gas turbine.

If Rudolph Diesel did not originate this plan, at least all the literature of the subject leads to him. He left behind him a drawing of a very simple revolving metal sphere set snugly in the cylinder head. In one side of this sphere was a depression, or measuring cup, and above it was a hopper of coal dust. The cup was filled with each revolution, and as the sphere turned, it injected its charge of dust into the hot, compressed air of the combustion chamber. There is no evidence that Diesel built such an engine, but one of his assistants, Professor Pawlikowski, was subsidized by the German government in recent years and actually built and ran a coal-dust engine, of much more elaborate design than Dr. Diesel's. Other German engineers have used not only coal dust, but ground coffee as an experimental fuel. Wear of engine parts caused by the ash residue is the greatest problem to be solved if the coal-dust engine is to become practical. Alan Chorlton, British engineer, reports that this damage has been greatly reduced by the use of special metals. Production of a practical coal-dust engine would be expensive, he says, but he believes that it would be cheaper than converting coal into oil.

Meanwhile, Bituminous Coal Research, Inc., an organization sponsored by American coal producers, has been investigating the Humphrey pump, which is another kind of coal-burning internal combustion engine. It is proposed for use at hydroelectric stations as a supplementary source of power when streams are low. Mounted at the foot of a dam, it would take the tail water which has already been through the turbines and with each explosion of coal dust, would force a column of water back behind the dam to do more work. This would be a cheaper way of producing auxiliary power, it is held, than burning the coal to make steam. It could also be used to pump irrigation and city water.

This work on powdered coal is proceeding on many fronts. If the fuel can be made to drive motors directly, the effect will be revolutionary.

Looking ahead to a distant time when all the trapped solar energy is exhausted, when petroleum, gas, shale oil, tar and coal have been converted into horsepower, man will still find fuels to burn, and ways to turn the wheels by which he lives. Nature took a million centuries to change plant refuse into coal and oil, but Professor E. Berl of the Carnegie Institute of Technology has found a way of duplicating the process in a few hours. From the cellulose of potatoes, sugar-cane, sawdust and weeds Dr. Berl has made, in laboratory quantities, good synthetic reproductions of the natural fuels. He estimates that about two per cent of the arable land in the United States would grow enough plant material to make the motor fuel the country used in 1941, and suggests that in tropical lands where plants grow lushly, sun-power could be converted into motor fuel most efficiently.

In many countries, all automobile gasoline must contain a percentage of agricultural alcohol distilled from corn or other crops, and corn-state leaders have proposed a similar plan for Americans. Alcohol may also be made from low-grade wood and sawmill leavings. With gasoline cheap and plentiful, this supplementary fuel has been too expensive here, but it may be adopted as prices increase.

Direct power from the sun?

But why use a vegetable middleman to utilize the power of the sun's rays, other scientists are asking. Why not capture the energy directly? Lionel S. Marks of Harvard estimates that if all the petroleum in the earth's crust were burned, its heat of combustion would be about equal to the solar energy arriving at the earth's crust in half a day, and that the heat of combustion of all our coal reserves would hardly match the energy delivered by the sun in six months. Direct use of this energy for limited purposes is already practiced in regions which receive much sunlight. In California and Florida, commercially manufactured solar heaters are mounted on the roofs of houses to supply hot water. John Ericsson, builder of the iron-clad *Monitor* of Civil War fame, constructed and ran seven "sun motors." Big mirrors concentrated the rays of the sun on cylinders filled with air or water, and the heat was made to turn wheels. He looked forward to the exhaustion of coal fields, and proposed that millions of his engines be used in tropical and semitropical regions.

At the Massachusetts Institute of Technology there is an experimental house which is kept comfortable even in the cold, New England winter by a solar-heating device on the roof. Glass-covered troughs trap the sunlight, which heats the water circulating through thin-walled metal tubes. The heated water goes to an insulated storage tank in the basement, which irons out the fluctuations in the variable heat of the sun. It would be simple to make this captured solar heat run a motor, but this would not pay as a commercial power source. Such power is like the gold in sea water, which costs more to extract than it is worth. To produce any usable amount of power, large areas of heat-traps would be needed, and the cost of equipment would be prohibitive.

Still another experimental method of capturing power from the sun has been devised by Dr. Eugene Rabinowitch, also of M. I. T. Sunlight is focused by a lens on a light-sensitive cell, and a tiny amount of electric energy is produced and stored. This device is of no commercial importance at present, but further investigations of solar energy are proceeding, under a special grant, both at M. I. T. and Harvard, and no one can say what discoveries the future may bring.

One of the most spectacular power projects of all time blossomed in the press in 1940, when Dr. Alfred O. C. Nier, twenty-seven-year-old physicist of the University of Minnesota, announced that he had isolated from uranium (derived from pitchblende) a small sample of the isotope known as U-235. One pound of this metal, it was reported, is equal in power to 15,000 tons of TNT and has as much energy as 5,000,000 pounds of coal or 3,000,000 pounds of gasoline. By an explosive chain reaction, this substance will quickly turn water into steam, and it was stated that a five-pound brick of metal would provide enough power to drive an ocean liner around the world. However, only a few hundred millionths of a gram of U-235 existed at that date, and immense difficulties lay in the way of producing a workable amount.

These are a few of the motors, fuels and schemes to which man may eventually resort for driving his ever-increasing array of machines. In addition to the energy stored in the earth and the direct energy of the sun, there is also the gravitational pull of the moon, which makes the tides by acting as a brake on the earth. Tidal dams may sometime be an important source of power, and if we are cautious, we may postpone the grim result of such a project described by J. B. S. Haldane in his fantasy, "The Last Judgment."

He hypothecates a time when man, having exhausted the supply of coal and oil, and finding power from water, wind and solar heat inadequate, builds great tidal dams which usher in a millennium of power and physical ease. But the dams so increase the braking action of the tide that the days grow longer, and the moon is pulled closer and closer to the earth. The satellite eventually bursts with a loud roar, and everyone quickly expires. We may be partially reassured by Mr. Haldane's estimated date for this occurrence—36,000,000 A.D.—but we should retain from his fable the notion that power is a rather important matter to people who live by machines, and that when a change is made in the methods by which it is produced, the world is never the same again.

PART THREE

NEW MATERIALS, NEW METHODS

CHAPTER ELEVEN

ARTIFICIAL RUBBER

Before World War II, the most vulnerable spot in America's economic and military armor was her rubber supply. With sixty-eight per cent of the world's motor vehicles rolling on our highways, we were using more than half of all the rubber produced in the world. Ninety per cent of our supply came from Far Eastern plantations controlled by Great Britain and the Netherlands and coveted by Japan, who had announced her expansionists ambitions with utter frankness.

For years our perilous position was known to every informed person. Ever since World War I our industrial and military leaders had been concerned about it, and there had been various attempts to break the stranglehold. Ford planted rubber in Brazil, Firestone in Liberia, Goodyear in the Philippines. Government silviculturalists made rubber trees grow in Florida; Edison produced rubber latex from goldenrod, and others experimented with milkweed juice. New methods increased the use of reclaimed rubber, and improved manufacture increased the life of the tire. Some of these attempts were successful in a limited way, but in view of our yearly peacetime requirement of about 600,000 tons, they were only a drop in the bucket.

More recently, rubber, chemical and oil refining companies, with the example before them of Germany's *ersatz* rubber industry, had been producing or experimenting with a number of synthetic rubber-like substances derived from such starting materials as petroleum, agricultural alcohol, coal and limestone. Man-made rubbers looked promising, but our production of all these substitutes in 1941 totalled a mere 12,000 tons—one-fiftieth of what we needed even before we had to feed the rubber-hungry maws of war machines.

Then came Pearl Harbor. The rubber supply which had cushioned our national life was suddenly cut off, and our very existence as a nation lay at the mercy of a dwindling stockpile—and the ingenuity of our technical men. To fill the yawning gap in our industrial economy caused by Japan's conquests, every possible source of rubber was exploited regardless of cost. Wild rubber was rushed from the Amazon, plantations still under Allied control were double-tapped, scrap was collected, and thousands of acres of latex-bearing guayule shrubs and cryptostegia vines were planted in California and Latin America. Every pound of this vegetable rubber was rushed into the breach, but it was clear that only one thing could save us—the quick creation of a tremendous new industry for the mass production by chemical methods of some resilient stuff that would behave like rubber. As Bernard Baruch's Rubber Survey Committee stated in its report, "If we fail to secure quickly a large new rubber supply our war effort and our domestic economy both will collapse."

In 1941, the large-scale production of these substitutes was only a gleam in the eyes of chemists and engineers. A few tires had been made of various synthetics mixed with natural rubber, and they stood up reasonably well in tests, but as for the best ways of making the test-tube rubbers, how best to process them and fabricate them into tires and how they would wear when turned out by the millions—these were all mysteries, and there were about as many theories as there were chemists.

Since then, we have been saved by the skin of our teeth from a nation-wide paralysis of vital transportation, and from a stoppage of transport on battle fronts which would most certainly have lost us the war. A miracle of research and production has taken place. In spite of delaying political wrangles and extremes of flamboyant optimism and defeatist gloom, the men of our rubber, petroleum, alcohol and chemical industries have managed to cram a program which might normally take a decade into about two years.

We have come through

Today, the new rubber industry, a unique accomplishment in the history of production, stands complete. In the summer of 1944, Rubber Director Bradley Dewey, successor of William M. Jeffers in coordinating the efforts of several hundred companies which have contributed to the vast enterprise, offered his resignation. The job was done. The new rubbers were being turned out at the rate of 836,000 tons annually—far more than we have ever consumed in a single year. And the curve is still ascending. In 1945, Col. Dewey estimated, manufacture would total more than 900,000 tons. Tires from test-tubes are not yet perfect and there are still difficult production problems to be solved, but we are now independent of the Japanese-held plantations. We have won the great objective without which all other battles would be lost.

This triumph of swift conversion has cost about three-quarters of a billion dollars, and it was accomplished during the worst period of material shortages in our history. Steel for rubber factories has been obtained in the teeth of other urgent demands. Production of rubber from petroleum has competed with the aviation gasoline program, since the butylene gases obtained in the refining process are needed for both products. So a part of the butadiene gas upon which most of the new rubber is based is now made from alcohol derived from farm products. This expedient has been a life-saver, but butadiene from alcohol costs about five times as much as that made from petroleum, and can be justified only as a wartime stopgap. The future of artificial rubber depends largely upon the magic by which a fraction of crude oil is chemically crushed, cooked, tortured and teased until it emerges at the end of the line as sheets of rubber hardly distinguishable from the product of the tree.

How buna-s is made

Fifty plants, many of them performing only one step in the entire program, have sprung up in various parts of the country. A few of them are integrated plants, located near oil fields, where petroleum stored underground for centuries is drawn through a series of monstrous and complicated refining columns, reactors and processing machines, and never sees the light of day until it emerges as rubber ready to ship to the tire factories.

One of the most spectacular of these continuous-process plants is located on a 1,200-acre lot on the east bank of the Mississippi near Baton Rouge. It is a part of the great Standard Oil of Louisiana refineries where high-octane aviation fuel and toluene for TNT are also produced. Crude oil from three states is pumped to the network of grumbling metal towers and broken down into components from which it is possible to make anything from an automobile tire to a lady's evening gown.

For oil is composed of an infinite variety of hydrocarbon molecules. Chemists will draw you pictures of them made up of "C's" and "H's" arranged in various patterns. Some molecules, with the carbon and hydrogen atoms rearranged, will make explosives, some will make plastics, some will improve an engine's performance, and others form the basis of artificial rubber.

The whole secret of making rubber out of oil is in juggling the "C's" and "H's" so that the right pattern eventually emerges. This may sound simple, but the equipment needed for the rubber program has cost nearly $50,000,000 in the Baton Rouge plant alone.

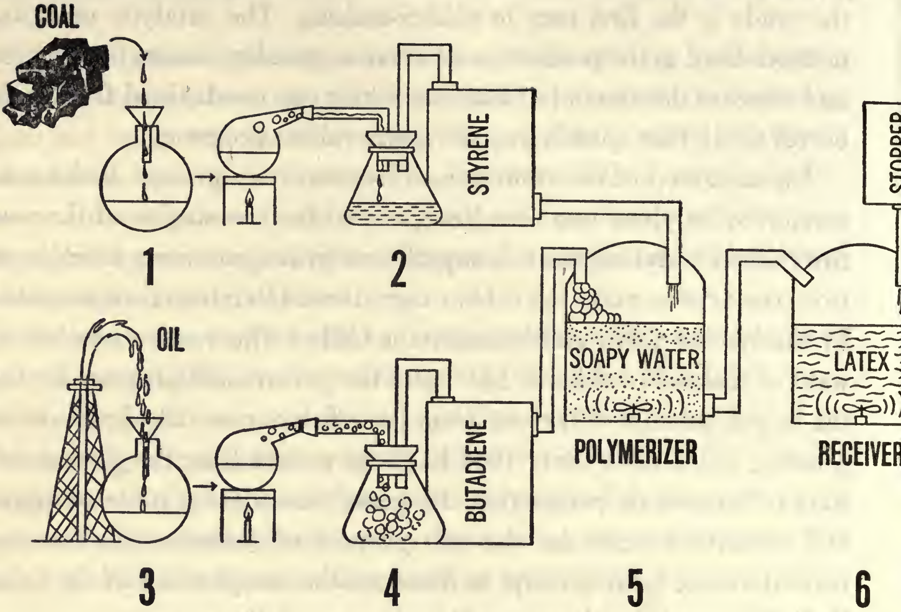
Many of the initial steps of converting petroleum into tires are similar to, or identical with, refining methods in making gasoline or other oil products. First, the crude oil has to be cracked to yield a series of major components, which range all the way from heavy sludge at the bottom of a 150-foot steel tower to valuable light gases at the top. Among these gases is butylene, and the extraction of this gas from the crude is the first step in rubber-making. The catalytic cracking methods used in the production of aviation gasoline hasten the process and increase the amount of butylene which can be obtained from each barrel of oil, thus speeding up the entire rubber program.

The next step of the continuous oil-into-rubber process is the conversion of butylene into butadiene, one of the two staples of the new tire rubber. Butylene has two superfluous hydrogen atoms which have to be removed to make the rubber ingredient. (Butylene is represented by the symbol C_4H_8, and butadiene is C_4H_6.) There are a number of ways of making butadiene, but under the government program by far the largest amount will come from the efficient new dehydrogenation process, which since early 1941 has been rushed from the glass retort state to large-scale production. Its great, bewildering maze of pipes and containers exists for the sole purpose of removing the two unneeded atoms. In an attempt to illustrate the complexities of the task, R. E. Wilson of Pan-American Petroleum put it this way:

"Imagine a big hall with ten billion fleas in it. They send you in with a sledge hammer and a crowbar and tell you to knock off the right hind leg and the left front whisker of each flea—and then when you've finished, to sort out all the fleas that you've maimed in the process."

When the colorless, invisible butadiene gas finally emerges, we are getting closer to the smell of rubber. That volatile gas, which would vanish in the air if not confined, makes up three-quarters of the tough, buna-s tire rubber that will soon be rolling on the highways. The other quarter is styrene, a liquid chemical which can be made from either coal or petroleum; its production raises no major difficulty.

The two gases are piped into another plant, where the ingredients are mixed and the rubber actually made. Here the stream of material gradually evolves from a scientific witches' brew that one must take on faith, and there are peepholes through which the newly born rubber can be seen. Big vats called reactors are filled with water, soap, styrene, HOW BUNA-S



This pictorial chart shows how buna-s, the artificial rubber used for tires, is made from oil and coal.

1 & 2. Styrene, a liquid, is a derivative of coal and is one of the hydrocarbon family, but of a different molecular structure than butadiene.

3 & 4. Butadiene is a gas composed of hydrogen and carbon. It is derived from crude oil and piped from adjacent refinery.

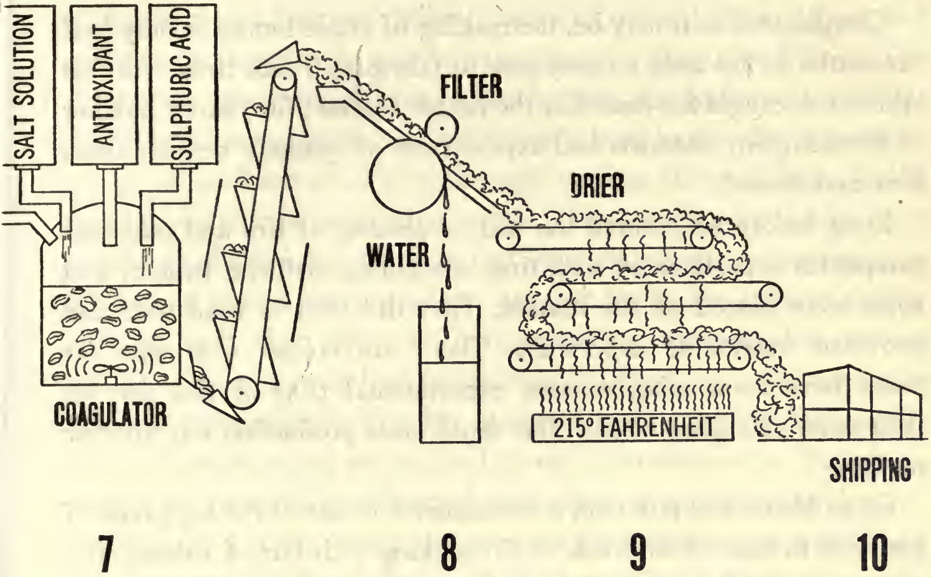
5. Here butadiene and styrene are mixed—three parts of butadiene to one part of styrene—in a solution of soapy water. In combining, they form a basic latex similar to that of natural rubber.

6. After the proper amount of chemical reaction has taken place, thoroughly uniting butadiene and styrene, a chemical is added to halt the uniting process.

butadiene and chemical "salt and pepper" and agitated by giant eggbeaters for sixteen hours or so, while the butadiene and styrene are encouraged to join hands in long chains to form the molecules of the buna-s tire rubber, otherwise known as "Government Rubber-S," or "GR-S."

A small part of the mixture always refuses to "jell" on its first trip through the reactor, and is separated and piped back to join the supply

ADE FROM OIL



7. An anti-oxidant is added to the liquid latex as a preservative. A solution of brine is added to aid curdling, and it is stirred by rotary paddles. The latex coagulates in small lumps, like cream when churned to make butter. Sulphuric acid washes away all traces of soap.
8. The small rubber particles are run through a filter which squeezes out the water.
9. Driers evaporate all remaining moisture in the artificial rubber. It is now ready for baling.
10. Buna-s leaves the plant in chunks ready to be processed into tires and other articles.
(Courtesy Dayton Rubber Manufacturing Co. Copyright, 1943)

lines. The rest comes out as latex. The work of the rubber tree has at last been approximated, for this white, milky liquid is similar to the stuff that runs into the cup when a plantation tree is tapped. The latex is run into a coagulating vat with a little brine and acid and stirred by a paddle, and rubber particles appear in much the same way that butter globules are formed when cream is churned. The new rubber is carried on endless belts through a wringer which squeezes out the water, and through a hot drier; then it is pressed and baled for shipment to the tire and rubber-goods plants.

Trials of tire-making

Complicated as it may be, the making of crude buna-s is only half the battle. It has been no easy task to fabricate it into tires. Not that Akron was caught flat-footed by the rubber famine; for years a number of tire-company chemists had kept abreast of synthetic developments here and abroad.

Long before we entered the war, a number of tire and chemical companies experimented with tires containing artificial rubber, and some were placed on the market. They did well in road tests and provided invaluable experience. There are rubber men who for years have been using various experimental tires of this sort on their cars, with good results. But rapid mass production was another matter.

Go to Akron and talk with a compounder in one of the big plants if you wish to hear of the trials of tire-making with buna-s rubber. The compounder is the master chef who brews the mix from which tires are made. He is the czar of tire-making. He sets the specifications, and when he puts his foot down, the vibrations reach plantations and polymerization plants, and changes are made. You see him in his shirtsleeves, cutting off a piece of rubber with his knife, smelling it, biting it, and stretching it. Then he either looks satisfied or worried. Laboratory tests give him a complete report on the sample, but a prodigious memory and a sixth sense born of years at his job often tell him whether the rubber will make a good tire.

Buna-s turned this man's world upside down. It was deceptive. It seemed all right but it had a will of its own. Before the war the skilled compounder knew the habits of rubber from every spot on earth, and knew how to blend and treat it to make it behave. Using batteries of chemical tricks invented by research men, he had increased tire mileage about 400 per cent in two decades. He had begun to think that he knew his job, and then they give him some stuff that wasn't rubber at all, but something like it, and told him to make tires from it on rubber machinery with men trained to work in rubber.

When treated like tree rubber, buna-s turned out to be so hard and unworkable that it took three times as long to make a tire. This rate of production would not fill the demand unless the industry tripled its number of tire machines, and with metals hard to get, that was out of the question. Buna-s can be made with various characteristics, so the compounders demanded softer rubber. This meant some sacrifice of quality in the tire, but there had to be a compromise somewhere, as there is in almost every product. Another headache: natural rubber sticks to itself when layers are built up on the tire mold; buna-s does not. The problem was solved ingeniously, by devising a semi-automatic machine which places a thin film of natural rubber cement between the plies. These examples are only a hint of the tribulations of the rubber chefs when their old reliable cookbooks became suddenly obsolete.

Company barriers were forgotten as the tire-makers pooled their resources to meet the challenge of the new material. They are emerging victorious. And the new tires are already nearly as good as those made from tree rubber.

How good are they?

This statement is not based upon guesses and hopes. Thousands of buna-s passenger-car tires have been tested on roads flat and hilly, curved and straight, wet and dry, paved and unpaved, and there are fat notebooks full of figures showing their performance under all conditions. A look at the record shows both pluses and minuses. The new tires may outwear natural rubber at high speeds, but often give somewhat poorer mileage at low speeds. They are more brittle and chip more easily. They hold the road much better on wet pavements than natural rubber, but since water does not lubricate them, they wear out faster under those conditions.

Balance the books and you can safely say that the average passenger-car driver can hardly tell the difference between the new tires and the old. The difference in wear is less than he now notices between his rear right tire and his front left one, and he has less trouble with skidding.

The making of heavy-duty tires for trucks and buses is a more difficult problem, and the whole industry is working toward a solution. Buna-s builds up more internal heat than tree rubber, and the bigger the tire the hotter it gets, with greater danger of fabric failure. This heat problem is being partially solved by using a special rayon in place of cotton cord to reinforce the tires. Rayon is stronger than cotton, especially when hot. By strengthening the tire structure, it reduces the amount of rubber needed, thus making thinner walls which carry off the heat faster, adding thousands of miles to the life of the tire.

Recent experiments indicate that nylon cords may make the big tires still lighter and cooler in operation. This weight-saving is especially important in the tires of military planes, where every pound saved increases range or load. At present, about thirty per cent of natural rubber is being used in heavy-duty tires. With much of the drain on our stockpile and imports being relieved by synthetics, this compromise will keep the big vehicles rolling until the war is won, or the fast-working research men solve the heat problem.

"The most important goal of the research efforts," wrote Rubber Director Dewey in his final report, "must be so to modify buna-s or develop a new polymer that (1) it will evolve less heat, (2) it will not lose so much of its strength at elevated temperatures and (3) when compounded for maximum strength it will have such resiliency that it will permit making tires that not only will heat no more than the old crude rubber tires, but will give the vehicle all of the 'soft ride' sought for in the pre-war tire." And he states that there is considerable promise that this goal will be achieved.

Rapid as the advance has been, chemists have barely scratched the surface in artificial rubber research. When war came, 300 different rubber substitutes were known to them. Buna-s seemed to be the most logical material for tires, and became the bulwark of the government program, but thousands of possibilities in this one synthetic remain to be explored. By varying formulas and processes, it can be made as soft as molasses or as hard as a plank, and a wide variation of other qualities can be built into it. Multiply this research program by 300, and bear in mind the limitless opportunities still latent in the hydrocarbon molecules, and it is easy to believe that man-made rubber will eventually be tailored at will to fill any need.

The long quest

There was a big backlog of research to aid the chemists in their work. A world in the grip of the East India rubber monopoly has been seeking relief for many years, and even before this problem arose, curious scientists of many countries discovered important facts about the nature of rubber. In 1860, Greville Williams of England distilled crude rubber and isolated its basic material, isoprene. It was found that, chemically, rubber and petroleum are close relatives. In the tree, carbon and hydrogen atoms are arranged in such a pattern that they form the rubber molecule. A different arrangement of these atoms beneath the earth results in the hydrocarbon molecules of petroleum. Soon Bouchardat of France took some isoprene and hooked its molecules together to change it back into rubber. A man named Tilden cracked turpentine in 1882, got something he thought was isoprene, and converted it into some rubber-like stuff. In 1910, Kyriakides, a chemist working for the Hood Rubber Company in Watertown, Mass., developed an artificial rubber, and at about the same time, Dr. Fritz N. Hofmann of Germany laid the experimental foundation for the buna-type rubbers.

And there were many others. Everyone knew that you could make rubber of sorts out of almost anything—cornstalks, sawdust, or an old straw hat. The Germans tried potatoes and the Italians tomatoes. The problem was to select the most adaptable, cheap and plentiful raw materials and work out a commercial process by which they could be converted at reasonable cost into a synthetic "elastomer" which would behave about the same as the natural type.

During World War I Germany tried out her first tires of buna-n. In this *ersatz* rubber, the butadiene was combined with acrylo-nitrile in place of the styrene later used in buna-s. The tires were a failure. Unless the cars were jacked up overnight, they took on the shape of lopsided doughnuts. When the Nazis launched their program of economic self-sufficiency in preparation for World War II, a more successful effort was made to supplant imported natural rubber (an easy prey of an Allied embargo) with the home-made material. Germany paid dearly for the transition, placing a 100 per cent import duty on crude rubber and using the proceeds to subsidize buna manufacture. The improved tire material, buna-s, was adopted. The failure of many of these tires is said to have caused traffic jams when the Nazis invaded Austria in 1938, but their technical men persevered and by 1941 a large part of Germany's rubber requirements was filled by synthetics. Before Germany went to war, small amounts of buna-s had been imported by the United States, and when the supply was cut off, the Standard Oil Company of New Jersey, by means of the much-discussed exchange of patents with Germany's I. G. Farbenindustrie, acquired the right to make both bunas. The buna-s patents have since been turned over to the United States government with the understanding that they are to be available under free license to American manufacturers.

Virtues of buna-n

While we use far more rubber for tires than for any other purpose, it has a vast number of vital uses in all manner of military and peacetime machines and appliances. A number of artificial rubbers which will not do for tires are admirably adapted to many of these special jobs. Buna-n was a failure when made into a tire, but it has other virtues which have saved the lives of many airmen. Oil does not rot it the way it does natural rubber, and that makes it just the thing for lining the new airplane tanks which do not lose their fuel when punctured with bullets. Two kinds of rubber are used in these tanks: an inner lining which resists oil, and a sandwich filling which sponges up quickly and fills the bullet-holes when the escaping gasoline strikes it. The construction is so effective that many planes have come safely home with their tanks riddled like sieves but only a few drops of fuel lost. Nearly two tons of artificial rubber are required to make the thirty self-sealing fuel tanks of the Superfortress. Another merit of buna-n—built into it by chemists—is that it remains flexible in the coldest weather. So it has a thousand and one uses for planes operating in the Arctic or in frigid high altitudes, where fuel connections and other rubber parts must withstand temperatures of sixty below.

And Butyl

Back in 1937 two young chemists named William J. Sparks and Robert M. Thomas spent a Saturday half-holiday in their laboratory at Bayway, N. J., and discovered the key to Butyl rubber, a promising synthetic now being manufactured under the government program. It does not wear as well in tires as buna-s, but research men have discovered that it holds air much longer. The result: better gas masks, better barrage balloons and life-rafts, and a promise of inner tubes that will have to be inflated only twice a year.

Nor should Butyl be dismissed as a future tire rubber. Tested on highways three years ago, Butyl tires ran only 5,000 miles or so. Then the compounders tried out thousands of recipes, and in recent road tests some of the tires covered 25,000 miles at forty miles an hour, with some rubber left on the treads. Because of the need of concentrating on a definite program, Butyl tires have been shelved for the duration, but if research men keep on improving them, they may eventually compete with buna-s. For Butyl can be made more quickly and cheaply. It is made directly from isobutylene cracked from petroleum, by-passing some of the expensive and time-consuming steps necessary in making buna-s. For this reason, some experts are predicting that Butyl may sell cheaply enough to enable it to wage a stiff battle, even with rubber from the tree.

Father Nieuwland's nose

The oldest, and in many ways the aristocrat of American artificial rubbers is du Pont's neoprene, which is made from acetylene obtained from coal. Neoprene owes its origin to the highly developed olfactory sense of the late Father Julius A. Nieuwland of Notre Dame University. Dr. Nieuwland had been experimenting with acetylene gas since his student days, and it was the memory of a peculiar odor smelled twelve years before that set him on the trail of a new derivative, called divinyl acetylene. In 1925 he met a du Pont man at a scientific meeting, and told him of the method he had developed for obtaining the derivative. Du Pont chemists had been trying with little success to make a suitable rubber substitute from acetylene, and Dr. Nieuwland's discovery gave them the essential first step. Combining this with another of his ideas, du Pont eventually produced neoprene, the first commercially successful artificial rubber. It was placed on the market in 1932, and production doubled year after year.

First-class tires were made from neoprene years ago, but its cost has barred it from this field. It can be made highly resistant to oil, sunlight, age and below-zero weather. It has many war uses where quality is paramount. For example, when today's fast, acrobatic fighting planes were in the blueprint stage, a new float-less carburetor was needed to make upside-down flying safer. The carburetor could not be made until the designers found a material for a gas-resistant diaphragm that would remain flexible and could be turned out uniformly with a thickness of a thousandth of an inch. A fabric coated with neoprene served the purpose as nothing else would. And it withstands the fierce sunlight of high altitudes so well that it is used to coat the rubber de-icers on airplane wings. The war curtailed production of neoprene waterproof garments, boots and shoes, hot-water bottles, tennis balls and dozens of other peacetime products. Tests indicate that neoprene washers for household water faucets will last for a generation without a drip, and this accomplishment by itself should assure a brilliant future.

Rubber-like plastics

There are also a number of new chemical materials—"stretchable plastics," they might be called—which are easing the shortage by doing many important jobs tree rubber used to do. One of these is the Monsanto Chemical Company's Saflex, once used in safety windshields and now used to waterproof Army raincoats. Another is Koroseal, developed by Dr. Waldo Semon of the B. F. Goodrich Company. It is made by another of those mystifying processes in which a formless gas is turned into a liquid, then into a powder, and finally emerges as tough, flexible stuff with some of the properties of rubber. Electrical insulation is now one of its most important wartime uses. Unlike natural rubber, Koroseal is not inflammable, so it is widely used in insulating wires in naval vessels. In case of a direct hit, fire will not follow the wires. Plastics of this sort are no mere rubber-savers. They are being groomed for many postwar uses which rubber was never equal to.

Dr. Patrick's accident

An accidental discovery made by a man who knew what he was about ushered in Thiokol, a chemical rubber with invaluable war uses. In the twenties, Dr. Joseph C. Patrick of Kansas City, a medical man turned industrial chemist, was trying to make an anti-freeze solution from ethylene gas, then a waste by-product of oil-refining. One of his mixtures thickened when he thought it should not, and the result was Thiokol, which the Dow Chemical Company is now manufacturing for the Thiokol Corporation. Thiokol is inexpensive and gasoline does not rot it—two facts which have boomed its production. Since 1940, the Navy has built a number of vast underground storage tanks to hold lubricating oil and high-octane aviation fuel. In anticipation of a steel shortage, it was planned to construct the great caverns of concrete. But aviation fuel depreciates in octane rating through contact with concrete, and there is some seepage through the walls. So the tanks were lined with large, black sheets of Thiokol, which were cemented like wallpaper to walls, floors and columns.

Now portable "gas stations" made of Thiokol holding up to 10,000 gallons of fuel or oil, are set up in a few minutes on foreign shores as soon as the troops land. Great supporting tubs of canvas reinforced with wood slats are staked to the ground, and inner bladders of Thiokol hold the fuel.

No matter how cheap and plentiful tree rubber may become in the future, it is clear that many of these man-made varieties designed for special purposes have come to stay. In a few short years they have been adapted to tasks from which natural rubber is barred forever, and it is fair to assume that they will be greatly improved.

The outlook for buna-s

The future of buna-s tires in competition with natural rubber is another matter. As a general rule, synthetic products become better and cheaper with the years, and it is reasonable to believe that buna-s will follow the same trend, that the tires will do as well or better than those of tree rubber at a cost that will not be prohibitive. In other words, we have shown Japan that we can get along without the rubber plantations which she has seized—permanently if necessary. We have also shown the lawful owners of these plantations that if they wish to sell their rubber after the war they must abandon their pre-war monopolistic gouging and assume a more responsible attitude.

Artificial rubber was spawned by war, but the research which has made it possible would have gone on steadily if Hitler had remained a house painter. The erratic behavior of the price of imported rubber did much to stimulate this research. To cite two extremes, once in the middle twenties it hit a preposterous peak of $1.23 a pound and in 1933 it sold for three cents a pound. The terms under which we have obtained our rubber in the past thirty-five years have a definite bearing on the future of buna-s.

To sketch briefly the recent history of natural rubber, the big boom in the Far East got under way about 1910, backed by British and Dutch capital. Before that, most latex came from wild rubber trees tapped by natives in the Amazon valley in the Brazilian state of Pará. When mass production of automobiles in the United States increased the demand, Brazilians attempted to profiteer. Rubber went to $3 a pound, and the result was frenzied planting in Netherlands India, Malaya and Ceylon. The Far Eastern planters not only captured Brazil's market—they used her own tree to do it. Many years before, seeds of the *Hevea braziliensis*, which Pará rubber comes from, had been taken to London, and the trees had been introduced in Ceylon. Soon they grew lushly in Malaya, Sumatra and surrounding tropical lands. The first shipment of cultivated rubber reached London in 1905, and when the boom came along, Far Eastern plantation rubber quickly pushed the Brazilian wild variety from the world market.

Heavy rainfall, "easy" labor conditions, freedom from the leaf blight which preys upon the tree in Brazil, and a bud-grafting process which increased the yield—these are some of the factors which have given world dominance to the Far Eastern rubber plantations and made them sources of fabulous profits. Until late in 1919 the price of rubber averaged well over fifty cents a pound. Millions of new cars rolled off the assembly lines, each using up about five tires a year, and war buying was tremendous.

Like American wheat farmers, the rubber planters over-expanded their acreage, and were caught by the postwar depression. At the same time, makers changed over from the old short-lived fabric tires to the more durable cord tires, thus cutting down the demand. There followed a series of crop-restriction schemes. There was the Stephenson plan, put into effect in 1922, which taxed all rubber exports over certain set quotas. This reduced surplus stocks so effectively that there was a shortage and a panic market, with rubber hitting the sensational $1.23 top in 1925. The plan broke down and was abandoned. After a period of chaos, an international rubber agreement was adopted, embracing all growing areas worth considering except Brazil, Liberia and the Philippines. By placing a premium upon efficient management, this plan favored the big plantations of Malaya and Netherlands India. When rubber was selling at about eighteen cents before the war, it was estimated that the average estate was making about eighteen per cent net profit, while estates with the highest yield were netting as high as thirty-three per cent.

The days of this bonanza appear to be numbered. After the war many hundreds of thousands of tons of natural rubber will invade the world market, if the Japanese have not girdled the trees, and judging by predictions, it will have to sell at a low price to compete with man-made rubber. Mr. Jeffers suggested eight to fifteen cents as a possible postwar price for buna-s, and Col. Dewey has mentioned twelve to thirteen cents a pound.

Since those predictions were made, there have been two improvements in the manufacture of buna-s which can hardly fail to reduce its cost. One is a continuous polymerization process announced by Goodyear. The butadiene and styrene molecules have been united in reactor tanks by the batch process, which means a waste of time in filling and draining the tanks. The new method, by which the measured ingredients are routed through the tanks in a continuous stream, will increase the output of plants by as much as forty per cent, report Goodyear engineers. Another time-saving method, the result of joint research by the General Tire and Rubber Company, the Carnegie Institute of Technology and Purdue University, is the mixing of carbon black reinforcement with the rubber in its liquid state, in place of the old method of grinding it into the solidified rubber in giant mills. This new method will cut milling time by one-third, it is claimed, and the rubber will be better because of the more uniform mix.

Still, many experts believe that the rubber growers can meet buna-s prices and still make a fair profit, and if the return of tree rubber is not deferred too long, harried tire makers will be delighted to work with their old familiar material. And while technical men feel confident that buna-s tires can be greatly improved, it is a matter of definite knowledge that the industry can make far better tires of natural rubber than we have ever seen. As a prominent chemist told the writer, "If heavy-duty tires were no better than passenger-car tires, there would be no trucking industry."

It is also worth noting that rubber scientists have not limited their work to synthetics—they have also been improving the rubber tree. Twenty years ago, a yield of 230 pounds of rubber per acre was considered good; by 1940 the better plantations were yielding 600 pounds, and there are acres of "prima donnas" which are producing 1,500 and even 2,000 pounds a year. Firestone has constantly increased its plantings in Liberia, getting high yields and cutting the sea haulage by 7,600 miles. In South and Central America, Goodyear, the United Fruit Company and the Department of Agriculture are conducting experimental plantations to combat the leaf disease and pave the way for the re-establishment of the rubber tree in its original home. Inexpensive equipment has been devised for the "family-size" rubber plantation which would give the small farmer a supplementary cash income like that of the Vermonter with his maple sugar orchard, and would stimulate postwar trade with our neighbors to the south.

To sum up, no one can state today with any certainty whether the tires of ten years hence will originate with the *Hevea braziliensis* of the plantation or the fractionating towers of the oil refinery. The race may be close, to the great satisfaction of the consumer. And rubber uses may increase so rapidly that both grove and refinery may flourish.

Ever since Charles Goodyear learned how to vulcanize rubber in 1839, its use has doubled with every decade. The war has brought a bumper crop of new applications. In many war vehicles, the twisting of rubber cylinders mounted near the axles takes up road-shock, supplanting metal springs. These may be adapted to peacetime automobiles. Sanitary air-foam cushions, used in tanks and planes, may make big inroads in the mattress and upholstery field. Inexpensive rugs and carpets with the nap fixed in a rubber base are waiting only for the victory. Conveyors of endless rubberized belts now carry minerals for many miles from mine to factory, and even rubber-surfaced streets have been proposed.

Artificial rubbers will be adaptable to many of the new uses, and even if the tire turns again to the tree, they will not become orphans. In addition, the new industry should serve two vital national purposes: it should establish a price ceiling for natural rubber to curb the rapaciousness of plantation barons, and it should act as a permanent insurance policy if an expansionist power should again attempt to stop American wheels from turning.

CHAPTER TWELVE

PARADE OF PLASTICS

THERE IS A WINDOW SCREEN READY for the postwar market which rolls up like a shade, and is as transparent as glass. It does not darken the room, as a wire screen does. It is actually tougher than wire, and it cannot rust. It is made of a new plastic.

After the war, bureaus will be sold with drawers that cannot stick in damp weather, and tabletops with lifelong surfaces which cannot be marred or stained by hot dishes, alcohol or strong acids. These pieces will be impregnated with a new plastic resin.

We are also promised trousers that will not wrinkle and will not lose their creases. There will be water pipes that cannot burst from cold weather, but will swell to accommodate the ice. There will be all manner of upholstery and drapery fabrics which will not shrink, stain, burn or support mildew, and which can be cleaned with a damp cloth. Plastics have made these things possible.

Building-panels for modern houses, impregnated with other plastic resins, will be light, strong, weather-proof and termite-proof. Used by themselves or in combination with older materials, plastics will make airplanes, automobiles, streetcars, busses and speedboats lighter, faster and more attractive.

These are a few of the thousands of uses, old and new, in which plastics of all kinds will take their place as soon as war demands slacken. For more than thirty years a few kinds of plastics have been used in the manufacture of electrical connections and in the making of toilet articles, gadgets and toys. But the word first captured the public imagination about a decade ago. Engineers and manufacturers had perceived the great implications of this class of synthetic materials, and advertising copywriters began to glamorize their prophecies.

The volume of plastics then produced was only a small fraction of the tremendous amount now being turned out by the chemical plants. When war began, plastics were used to supplant scarce metals. Then the chemicals used to make plastics became scarce, and at the same time, more vital uses were found in which plastics were needed because of their own particular properties. Soon more than eighty-five per cent of all these chemical building materials were being snapped up by makers of warplanes, jeeps, gunstocks, bayonet scabbards, waterproof clothing, canteens, helmet liners, medical equipment and other essential articles. Accurate figures are lacking, but an estimate that the production of plastics has increased tenfold in the last decade is conservative.

Plastic "castles in the air" have long cast their filmy shadows over the world of tomorrow. Just as Charles Goodyear proclaimed in the mid-1800's that even pianos and walking sticks would be made from his newly vulcanized rubber, enthusiasts have envisioned an all-plastic civilization, completely forgetting the cheapness, availability and other desirable qualities of such old standbys as wood, steel, cement and glass. These zealots have often miscast their industrial pin-up girl, to her great harm. Plastics do not constitute a "universal material." But in an increasing array of applications, one or more plastics can be found which will do a job that no other material can do as well, or can do at all. And the range and versatility of plastics are rapidly increasing. In the decorative field, they are adding new color, curves and sheen to everyday objects. In functional uses they are achieving new triumphs just as impressive, if not always as spectacular, as the gaudy dreams of the "imagineers."

By tracing a few of these plastics from the first surmise of a chemist through the experimental and development stage to actual use we can get some idea of the phenomenal rise of these new materials. The window screen mentioned can be made from a number of synthetic compounds, but it was first made from "saran," a new plastic developed by the Dow Chemical Company. It took Dow's chemists about seven years to nurse this plastic from its laboratory birth to industrial maturity.

Born by accident

The whole thing started with a customer's complaint. A gallon can of dry-cleaning fluid was sent back to the plant because it had solidified and could not be used. The sales department sent the can of tough, rubber-like stuff to the laboratory, and the research men went to work. They tried to dissolve the mess, but could find no chemical that would break it down. They tried to find out what had solidified the liquid, but could only guess. They only knew that some agent—possibly heat and the solder in the can—had accidentally polymerized it; that is, had made big molecules out of little ones, thus changing it to solid form.

No chemist is ever satisfied until an "accident" like this is explained, and when an unusual substance is produced it is second nature for the men of the big chemical firms to ask, "What can we do with it?" The laboratory men found the answer. This was a plastic of great possibilities. It could be molded, forged, tempered, and, in many respects, worked like metal. It could be made into strong cord, or converted into a tough, pliable material like tanned leather. It was clear that this plastic had a great number of uses. Tentative interest ripened into the kind of conviction that prompts corporations to spend money. The project grew steadily until fifty chemists were working on it, and at length, prophecies were fully justified.

Saran first appeared on the market in the form of tough, attractive woven belts and suspenders, fishing leaders and seat coverings. The seats of some subway cars in New York were covered with it. Colored an attractive light brown, they look like woven cane or straw, but they wear, literally, like iron. Spill whatever you like on them, and they will not stain. In one of the Dow tests, saran fibers were soaked five years in a jar of sulphuric acid—which will eat through almost anything—and they emerged from the ordeal only slightly damaged. It is as flexible as rubber, and is tasteless, odorless and non-toxic. The last-mentioned quality is important in any plastic which comes into contact with the skin, for a few people are allergic to some plastics, just as some people get a rash if they eat fish. Firms which develop pliable plastics like saran usually make a number of watch straps and ask volunteers in the company to wear them a few months. Saran gave no trouble.

Saran is known to chemists as a vinylidene chloride resin. Michigan brine and petroleum are its basic raw materials. The whole Dow industry was built upon the brine wells near Midland. The chemists take the brine apart, and experiment with the ingredients to find out how they can be used. One of the products is chlorine, and this was combined with ethylene—obtained from petroleum—to produce saran in its intermediate liquid phase.

When chemists first examined the can of solidified solvent they thought they had made a new discovery, but other chemists, upon investigating the literature of synthetic materials, found that a Frenchman named Regnault had produced it in 1838. Regnault himself had discovered it "accidentally," by which we mean that he was not looking for a liquid compound which could be changed into a solid. Its discovery was an unintended and incidental side-issue of chemical experimentation leading toward a different goal. No true scientist ever ignores an unexpected result, and Regnault wrote a paper about his new compound, with no idea that it would ever be of any practical use. He noted that this liquid, which is called a "monomer" because it is composed of small and simple molecules, became cloudy after it had stood awhile. We now know that this happened because the tiny molecules were slowly joining hands in long chains to make the huge, complicated molecules of a plastic. In other words, it was being slowly transformed from a liquid to a solid. Dow chemists devised ways of hastening this process of polymerization, and the white precipitate which had given Regnault's compound its cloudy appearance was removed as a chalky powder, combined with other chemicals, and treated to form a commercially valuable synthetic resin.

The list of articles which can be made from this plastic alone would form a long and impressive catalogue. There are now many types of saran, made by slightly different recipes. It can be made in flexible, translucent filaments which will take color well and can be woven to take the place of leather—for the vamp of a woman's sport shoe, for instance. And it can be made as hard as a board. It is made into tubing to carry water, oil, or chemicals, and these pipes are being used in industrial plants and laboratories. Two sections of this plastic pipe can be welded by applying the ends to a hot plate for a few seconds, melting them slightly, then sticking them together. And, as mentioned above, if water freezes in them, the pipes will swell, not burst.

Saran is mentioned specifically as a good example of a newly developed plastic, but plastics based on the same recipes are made by other firms. Velon, developed by the Firestone Rubber and Latex Company, is also a vinylidene chloride plastic, and from it are made similar products, including window screens. And flexible screens can also be made from the nylon which, when processed differently, yields hosiery and parachute fabric.

Semon's golf ball

A close relative of the saran group is the B. F. Goodrich Company's vinyl chloride resin which goes under the trade name of Koroseal, and its development was also an alert capitalization of the unexpected. In 1926 while he was working on a new adhesive, Dr. Waldo Semon of the Goodrich research staff turned out a little resilient amber stuff that aroused his curiosity. He pressed some of it in a golf ball mold which happened to be in his laboratory and walked down the corridor bouncing it on the floor and calling for witnesses. Since the stuff could not be vulcanized, it was obviously unsuitable for golf balls, but after years of experimental work, Koroseal was perfected in the form of a durable, leatherlike, flexible plastic which can be made in all colors for a wide variety of uses. Its raw materials are coke, limestone and salt. From them is obtained vinyl chloride, a volatile, sweet-smelling gas. This is refrigerated to liquefy it, then with the aid of a catalyst, the small molecules are linked together into big ones, and the result is a fine white powder—the flour for the "dough" which by heat and pressure is converted into the finished plastic material. Before the war, this plastic was used for a number of jobs like the water-proofing of shower curtains and raincoats. Tubing is made from it similar to that made from saran. Among postwar possibilities are a liquid preparation which can be sprayed on floors, to harden like linoleum, and the "run-proofing" of hosiery. This may be done either by coating stockings with the invisible synthetic, or by using one thread of it with every two of fabric. Heat melts the synthetic slightly and forms a firm bond where the threads cross.

By this time it should be clear that plastics are not usually devised by research chemists who have definite instructions to find a material that will do this or that job. Much has been said by industrial publicists about "man-made materials tailored for special tasks," but this is putting the cart before the horse, at least during the early stages of discovery and development. More often, a research man, who may not be thinking of plastics at all, observes a curious chemical behavior, makes a hunk of stuff that may have possibilities, and reports the matter.

Scientists loathe the phrase "accidental discovery," and they cannot be blamed. It demeans their craft with its implication that anyone could have invented the new machine or material if he had had the luck to stumble upon the secret. They correctly stress the fact that only a trained scientist would be likely to understand the significance of an unexpected finding, would know how to repeat the steps which produced it, or would be able to correlate it in its field. Yet they must admit that in the field of plastics, the approach of the scientist has been oblique, to say the least.

Often as not the discoverer has been unwittingly duplicating the experiment of a chemist long dead, and later finds a record of his work in the scientific archives. Sometimes he finds that his "new" plastic has been previously patented by another firm here or abroad, and a license has to be obtained before manufacture can proceed.

The bottle in the sun

One of the many approaches to the glamorous transparent plastic known to chemists as methyl methacrylate, and to the public as Lucite or Plexiglas, took place in an old laboratory on the bank of the Brandywine River some years ago when a du Pont chemist was trying to find new commercial outlets for certain by-products of methanol (synthetic wood alcohol) manufacture. He had a bottle of a colorless liquid compound similar in appearance to water, but deceptively complex in its chemical composition and ancestry. It was a methyl methacrylate monomer. Methanol played a large part in its creation, and everything in it came originally from coal, air, water and salt. The chemist put the bottle on a sunny window sill and temporarily forgot about it. When he finally returned to it, the liquid had set to a clear solid. This behavior prompted a line of research which resulted in the commercial development of the widely publicized Lucite. Instead of waiting for the heat of the sun to link up the little molecules of the liquid monomer into the long chains of a solid, chemists use a catalyst, which brings about the change more rapidly and controls it more accurately.

But this was not the birth of the famous plastic. So-called acrylic resins of this type were first made in German laboratories decades ago when other curious chemists obtained results which they did not understand, and then found that they had some stuff that would behave like the materials we call plastics. More work was done in England. The Rohm and Haas Company of Philadelphia, obtaining, as did the du Pont company, the right to use the foreign patents, brought out Plexiglas, which has similar properties.

Thus the new plastic grew. About 1938 it swam into the public ken on a towering wave of publicity, and since then it has justly occupied a prominent place in the plastics parade. Its use in bomber noses and "blisters" is one of the best examples of the value of a plastic. The traditional material for a window is glass. It is cheap and easy to set in place, and it is highly unlikely that anything else will be used for ordinary windows in the discernible future. But suppose you want a curved window which will be frequently exposed to bullets. Glass is hard to fabricate in quantity in large, curved surfaces, and bullets shatter it. Here a plastic finds its niche. The conical nose-pieces of acrylic resin are tough and shatter-proof, both in the factory and in flight. A bullet leaves a clean, round hole which is easy to patch. And as an additional dividend, this plastic is more transparent than even high-quality plate glass—an important aid to crewmen. In all these ways, the plastic is superior for this particular use. But no material is perfect. No plastic yet made is as scratch-proof as glass. For this reason, abrasion caused by flying particles of sand limits the life of a bomber nose.

Because of its crystalline structure, this acrylic plastic has another neat trick. Fashioned into curved rods, it will "bend light around a corner." The light goes in one end and comes out the other. Doctors and dentists use it to obtain a clear view of the human interior, and it is used in highway reflector buttons throughout the country. Other light-transmission uses are being tested experimentally. Advanced architects suggest, for instance, that rods of the plastic may be used to "pipe" light throughout a house from a single light source.

The light-transmission properties of this plastic make it the equal of fine optical glass for spectacles and lenses. Shatterproof "contact lenses" for the eyes are made from it. From this and other plastics, successful optical lenses have been made for various instruments. Plastics may greatly reduce the price of spectacles in the future. Glass lenses must be ground and polished—slow and expensive operations—while lenses may be pressed out of plastic in a mirror-smooth steel mold, with no polishing needed.

This plastic is also used—in peacetime—to add attractiveness to a wide variety of articles which may also be made from other plastics, or from rubber, wood or metal. Among these articles are brush-backs, decorative boxes, table tops, pipe stems and fountain pens.

Another special use of a plastic, where nothing else will do, is in the manufacture of shatterproof automobile windshields. "Safety windshields," in which two panes of glass enclosed a transparent plastic sandwich, were adopted a number of years before the war, and injuries due to accidents were reduced because glass particles clung to the plastic sandwich-filling in case of breakage. But the cellulose plastics which were first used became brittle in cold weather and offered little protection. Then a vinyl butyral resin, which is strong and elastic at all temperatures, was introduced. Called "Saflex" if it is made by the Monsanto Chemical Company, and "Butacite" if made by du Pont, it was used between the two panes in a layer less than one-fiftieth of an inch thick, and real safety glass was the result. Now this plastic has been largely taken over by the government to waterproof Army raincoats and other coverings, but wider use awaits it after the war. For people in hazardous occupations, safety spectacles may be made, with double lenses sandwiching a thin layer of the plastic.

These are only a few of the important newcomers in the big plastics family. There are other plastics which are produced in far greater volume, and have displaced older materials in many fields. But these are cited particularly as examples of plastics which do special jobs as plastics, and cannot be called substitutes.

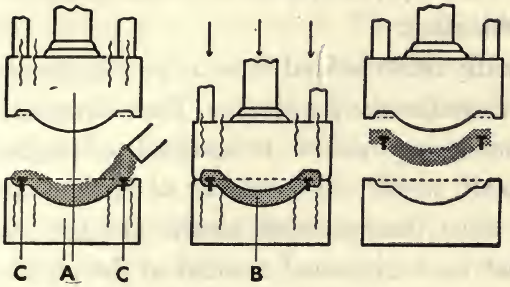
What plastics are

Before going further, we should stop and consider the question: What *is* a plastic? Strictly speaking, it would be possible to apply the word to any kind of doughy material that can be given permanent shape by heat, by pressure, or by both. By this broad definition, brick buildings, concrete roads, glass window panes, and even steel knives might be called plastic products. But people in the plastics industry do not consider them so. While there is no universal agreement on a definition, most experts take the attitude that a plastic is a chemical product, with all or a part of its ingredients produced by synthetic methods. This definition is wide enough to include the important cellulose group of plastics, which utilizes cotton linters and wood fiber as raw material, to include plastics in which all manner of fillers like wood flour, rags and paper are introduced, and to cover the "natural" plastics like those obtained from milk, soybeans and coffee.

Regardless of their origin, all plastics are divided into two major types, the *thermoplastic* and the *thermosetting* varieties. A large group of plastics like saran, Koroseal and Lucite belong in the thermoplastic group, which means that articles shaped from them by means of pressure and heat will become soft again if they are heated to a high enough temperature, the required temperature varying with the nature of the plastic. This is often an advantage. The saran pipes, for instance, could not be welded "on location" by means of a hot plate if saran were not thermoplastic. And it may be a disadvantage. If you touch a lighted cigarette to the new plastic screen, the strands will disintegrate from the heat, leaving a clean, round hole.

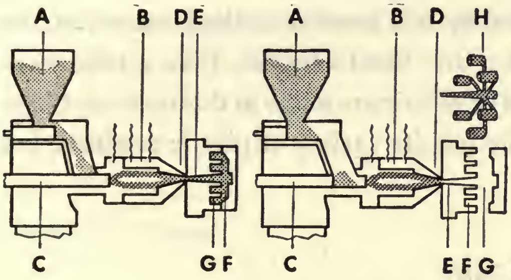
The other major group of plastics is called *thermosetting.* Such plastics are soft when heated in the process of fabricating articles, but when

HOW PLASTICS ARE MOLDED



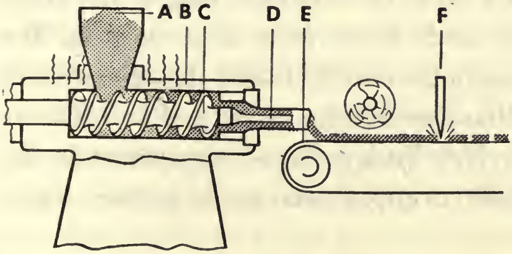
COMPRESSION MOLDING

Precisely measured amounts of plastic compound are placed in heated, polished steel molds (A). As molds close, compound (B) is softened by heat to sticky mass which flows to all parts of molds. With thermosetting plastics, a short cure in heated molds will harden compound permanently. With thermoplastics, molds are chilled to harden material. Any metal inserts (screws, etc.) (C) are carefully placed in molds when filled. Chief advantage of compression molding—large objects (up to 20 lbs.) can be made.



INJECTION MOLDING

Powdered thermoplastic molding material is fed automatically from hopper (A) into heating chamber (B). Here heat transforms powder into freely flowing, near-liquid mass which is forced by ram (C) through nozzle (D) into passage (E), then through inlets (F) into cold mold cavities (G) where it solidifies in shape of mold. While one finished piece is being ejected (H) new charge flows into heating chamber. Half a dozen small, round articles are thus pressed at once, then the connecting branches are cut off and reused. Finished articles are often ejected as fast as six times a minute—much faster than by compression molding.



EXTRUSION

This method has become important recently in molding continuous rods, tubes and strips of almost any thickness needed. Granules of thermoplastic material are fed from hopper (A) into the heated machine body (B) where heat transforms material into a semiliquid mass. This is then forced by a mechanical screw stuffer (C) through a die of the desired shape (D) onto a conveyor (E) which travels at carefully regulated speeds. As the extruded strips cool and harden they are then cut into specified lengths (F) or wound into coils.

(Courtesy Monsanto Chemical Company.)

they cool, they harden permanently and can never be melted again. Plastic ashtrays, restaurant table tops, telephone receivers and electrical connections belong in this class.

These products are not usually made in final form by the big chemical firms which develop and manufacture the plastics. These firms sell the plastics in the form of "molding powders" to hundreds of plastic molding firms, great and small, which use a number of methods to make the finished articles. Most thermosetting plastic articles are molded by *compression*. That is, a measured amount of the plastic material is placed in a heated die of polished steel and stamped in the desired shape. By the newer method of *injection* molding, used with thermoplastic materials, the melted plastic is forced into a mold and cooled to make it harden. And by still another method, *extrusion*, the hot plastic is forced through a die, like toothpaste from a tube. Continuous rods, tubes and bands of plastic are made in this manner. Other methods are used to create the infinite variety of plastic products, but these are the main ones.

Elephant tusks and billiard balls

We are now ready to face the fact that plastics are not very new, and that hunters armed with elephant guns and indoor sportsmen armed with billiard cues had quite a bit to do with their origin. The ivory from which billiard balls are made comes from elephant tusks. The elephants were shot off so fast in the middle 1800's that the price of ivory went skyrocketing. Billiardists felt the pinch, and in 1868 the firm of Phelan and Collender, New York makers of equipment for the game, offered a prize of $10,000 to anyone who would produce a substitute for ivory.

John Wesley Hyatt, an Albany printer and amateur inventor, was among those who heeded the call. With the help of his brother, Isaiah, John Hyatt set up a crude laboratory and worked nights and Sundays to win the prize. He spent several years in trial and error, and no one knows how many messes of "dough" he mixed and discarded before he finally got on the right track. There is no record that Hyatt ever made a satisfactory billiard ball, or won the prize, but without the facilities or the training of a chemist, he invented the first man-made plastic. His original goal became a side issue as he continued his crude experiments. He brewed a stew of ordinary cotton, nitric acid, camphor and alcohol. He heated it to a soft, sticky paste, and put some of it under a heavy weight. When it cooled, it was hard, durable and pleasant to the touch. He asked his brother to name it, and Isaiah, who was an editor, called it "Celluloid."

Hyatt went to Newark, N. J., and started the Celluloid Company, and the country was soon flooded with celluloid collars, dental plates, piano keys, toilet articles, baby rattles and campaign buttons. The company has been growing ever since, keeping abreast of the latest developments in the field.

Parson's dilemma

At about that time, the Reverend Hannibal Goodwin was having trouble in the Sunday School room of his Newark church. The glass stereopticon views of the Holy Land which he used in his lectures were always breaking, and he wondered if unbreakable plates could not be made from John Hyatt's new discovery. When he found that no transparent celluloid had been made, he bought some chemicals and set to work in the attic of his parsonage. Mrs. Goodwin and the children spent nervous evenings, for every now and then an explosion shook bits of plaster from the ceiling. Visitors to the Broad Street house may still see scars made by flying glass on the attic walls. But the minister persevered, and soon he took out a patent for transparent nitrocellulose film which could be wound on spools. Mr. Goodwin not only got his shatterproof stereopticon plates—he paved the way for the movies.

The film which he obtained is now used by the entire motion-picture industry.

Hyatt's celluloid has found many new uses since those days, but it has one important disadvantage, as the Goodwins discovered. Based on nitrocellulose, it is inflammable. For decades parents warned their children about it, and the industry searched for a fire-resistant celluloid-type plastic. Such a plastic existed, but it was not brought into general use until the late twenties. Then Hyatt's old company—now the Celanese Celluloid Corporation—the Tennessee Eastman Corporation and other firms brought out the now famous cellulose acetate plastic. Instead of adding nitric and sulphuric acids—items in the perfected celluloid recipe—to the cotton cellulose, they used acetic acid and acetic anhydride, two chemicals which may be made from coal. This plastic does not flare like celluloid at the touch of a flame, and it burns no faster than hard wood. It was quickly adopted for home movie films. Hollywood does not use it because of its higher cost and for certain technical reasons, but it has made home motion pictures a safe hobby for the amateur. Other versions of the safer cellulose plastic soon followed. The Dow Chemical Company and the Hercules Powder Company varied the recipe by mixing the cellulose with a chemical made from brine and petroleum, thus producing the ethyl cellulose plastic of like behavior.

The cellulose types now account for a large slice of entire plastic production, and it is hard to conjure up a picture of everyday life without them. Older women remember when buttons cost three times their present price and were sold in only a few colors and designs. Today they appear in an infinite variety of shapes, sizes and colors. Automobile steering wheels, doorknobs, knife handles, flashlights, compacts, jar tops, fountain pens, radio knobs, fishing reels, costume jewelry and a thousand other things are more attractive, varied, and inexpensive because of John Hyatt and those who have followed in his footsteps.

Hyatt and Goodwin were not the only experimenters whose efforts to solve small problems changed the living habits of millions. There was Dr. Adolph Spitteler, a teacher of Hamburg, Germany, who tried to make a white writingboard as a substitute for his classroom blackboard. He fiddled with many chemical mixtures with no success, and then one day he hit upon the idea of mixing sour milk with formaldehyde, a colorless gas then used chiefly for fumigation. The result was a shiny, hornlike substance, the first casein plastic, which is now used as a manufacturing material throughout the world. Recent research has made it possible to use soya beans, lignin from wood, peanuts and various other vegetable products in place of milk. Rods and tubes made from this plastic are easily machined into all manner of small ornamental objects.

Creator of Bakelite

The greatest pioneer in plastics was the late Dr. Leo Hendrick Baekeland, who in 1907 combined phenol (carbolic acid) with formaldehyde to make the plastic which now leads all others in commercial use. Dr. Baekeland's patents expired in the middle twenties, and his plastic is now manufactured by many firms under many trade names, but it is best known by the name its discoverer gave to it—Bakelite.

It is almost an axiom that the inventor of a plastic is looking for something else, and Dr. Baekeland was no exception. His life was an amazing success story. A brilliant and penniless young teacher of chemistry in Belgium, he came to the United States to make money. After a severe struggle complicated by illness, he invented a photographic paper which could be printed in artificial light. Sunlight had previously been used for printing. George Eastman of the great photographic firm called him to Rochester and announced that he wished to buy his "Velox" paper. Baekeland would have taken $25,000 for his invention, it is reported, but Eastman opened with an offer of $1,000,000.

Baekeland took his million and set to work again in his laboratory. He was curious about the manufacturing process used by a little red bug in India. The bug sucks the sap of fig trees and converts it into a protective covering for itself. This covering is the source of shellac. Dr. Baekeland set out to make a synthetic resin to take the place of shellac. After many experiments, he produced a tough mess from phenol and formaldehyde which nothing would dissolve into anything like a varnish resin. Greatly impressed by the obstinacy of the material, he at length abandoned his attempts to bend it to his will, and instead capitalized upon his failure. Using heat, pressure and a catalyst to assist the reaction, he converted the mess into a clear liquid which quickly hardened into an attractive amber substance when he poured it into a mold. The hard, thermosetting plastic turned out to be very fire-resistant and a poor conductor of electricity. It soon found a huge market in the manufacture of molded parts for electrical equipment. That was only the beginning.

Dr. Baekeland predicted that his new plastic would be used in forty-three industries, but its development has exceeded his wildest hopes. It is molded and cast into countless things we see all about us, and where special strength is desired, it is used in the making of laminated sheets—one of the most promising of the many plastic products. For this purpose it is prepared in liquid form, and sheets of paper or cloth are dipped into it repeatedly until several dried layers of the plastic cling to them. Then the sheets are molded together under tremendous pressure and heat, and there emerges a single panel of material, rock-hard and lustrous, which may be used for a table-top, a bar, or a decorative wall covering. Paper and phenolic resin are also combined to make gearwheels. Timing gears of this type have been used for years in automobiles, and now there are even factory gearwheels of laminated plastic, which use water instead of oil for lubrication.

Dr. Baekeland's phenolic resin is also used to stick thin sheets of plywood together in a bond that heat, cold and rain cannot dissolve. Use of bonded plywood has increased rapidly during the war. The famous PT boats are light, roomy and fast because of this new technique, and construction time is saved because much of the caulking once necessary is eliminated. Light, strong, and easy to ship, bonded plywood has been used to build all manner of temporary wartime buildings, and architects foresee dwelling houses with walls made of double bonded-plywood panels enclosing a layer of insulating material. Plastic resins, including Dr. Baekeland's and others developed later, may find their greatest success in the sky. The wings, fuselages and tail assemblies of training planes, glider planes and cargo planes are made of the plastic-plywood, at a great saving in metals and man-hours. In building the plane of the future, many materials will fight it out in the market place. Bonded plywood will be an important contender.

New plastics and new ways to use them have been pouring forth rapidly from the laboratories of the big chemical firms in recent years. New ideas are the lifeblood of chemical production, and in a pre-war survey it was shown that out of every $100 of sales, these firms were turning from $2.50 to $5.00 back into research. These allocations have stimulated the discovery and development of new plastics. In the early twenties, the only plastics commonly heard of were celluloid, bakelite and casein. Now there are scores of varieties, each adapted to somewhat different uses. Plastics compete not only with older materials, but with each other.

Rainbow hues

The phenolic plastic is a grand material and holds its place, but it does not take color well. Articles made from it must be yellowish, brown or black. This was one of the reasons for the immediate popularity of the urea-formaldehyde plastic which first appeared in 1928. It will take any color of the rainbow. Urea is used in place of phenol in this plastic, and the wide use of this white, crystalline powder is possible because of the enterprise of the du Pont company in establishing domestic manufacture of the chemical by synthetic methods. Once, all the synthetic urea used in this country was imported from Germany, and in 1920 the price went as high as fifty-seven cents a pound. Du Pont chemists took some by-product carbon dioxide, treated it with ammonia to make urea, and set up large plants to turn it out in quantity. Today all our urea, which has a startling variety of new uses, including a protein substitute in cattle feed, a powder to heal wounds, and a starting material for a poison-ivy killer and a flameproofing compound, is made in this country and sold for less than four cents a pound.

This plastic, like all others, is now restricted to war uses. Like Dr. Baekeland's phenolic variety, the urea-formaldehyde resin is used to make the light, weatherproof bonded plywood used in PT boats, planes and buildings, and the plastic has a hundred other wartime uses. To the public it is best known in the form of the vividly colored, lightweight, shatterproof cups and plates which go by the trade name of "Plaskon" and "Beetleware." It is used for radio cabinets and many other everyday objects in which bright colors and durability are desired, and in its translucent form it is made into reflectors and globes for electric lights.

Transmuted wood

Plastics are not always a rival of other materials; often they supplement them, as in boats and planes. In the newest use of a urea compound, wood is treated so that it is no longer wood at all, but a completely new material superior in many ways to both wood and plastics. In a tabletop made of this "transmuted wood," the "finish" goes all the way through; spilled coffee or cocktails, hot dishes and scratches lose their terror. Such furniture will survive almost any outrageous treatment. You can soak it in water and it won't warp. And in spite of its iron constitution, it will have a satin-like sheen displaying the natural grain of the wood.

In this process, the wood is impregnated, under pressure, with a cheap, colorless, odorless chemical compound known as methylol-urea. The impregnating solution is made by dissolving two powders in water in the required proportions. One powder, di-methylol-urea, is made by condensing formaldehyde with urea, the other is urea itself. The wood to be treated is placed in a big steel cylinder, and the solution is pulled in through a pipe by pumping the air out of the cylinder. The chemical combines with the components of the wood to form the large chain molecules of a plastic, and hardens, filling the tissue. This fortified wood is only slightly affected by water; since the plastic is thermosetting, it cannot be softened by heat, and it has hardness, fire-resistance and possibilities of finish unknown in the untreated wood. To produce a hard, smooth finish which will take a high gloss, it is compressed in a heated mold with a mirror-like surface. No further finishing is needed. Since it cannot warp, shrink or swell, this wood-plastic may end forever the nuisance of the sticking bureau drawer. In tests conducted over a period of two years it has broken the heart and jaws of every hungry termite which has been introduced to it. And furniture is only one of its many uses.

It is also easy to give the wood a permanent dye of any color. The dye is simply added to the chemical solution before it is drawn into the cylinder containing the wood, and the color permeates the wood completely.

The new material was developed by a group of du Pont chemists headed by Dr. J. F. T. Berliner, who acknowledges a heavy debt to government scientists at the U. S. Forest Products Laboratory at Madison, Wis. In a series of experiments which began several years ago, the men at Madison found that by sprinkling crystallized urea on green lumber they could prevent it from checking and cracking while it seasoned, and they also found that by soaking the green lumber in a solution of urea they could bend it at will when it was heated. To prevent the wood from softening again under further heat and losing its shape they added formaldehyde to set it. This resulted in permanently curved wood sections of great strength. The wood was given some of the properties of plastics. Meanwhile, Dr. Berliner and his colleagues, investigating other compositions of urea and formaldehyde, developed the methylol-urea solution and the method of impregnating the wood with it.

This discovery comes at a time when the country is faced with a critical shortage of lumber because of the great demands of the war. We are cutting many of our best woods faster than they grow, but we are using no more than fifty out of about 1,000 varieties of wood available, and we are discarding poorer grades of the usable woods. The new chemical treatment will take woods now ranked as inferior because of softness or weakness, and transform them into hard and durable materials which will ease the demand on the grade-A varieties. Soft maple, yellow poplar, tupelo gum and several varieties of soft pine can be treated to replace hard maple, oak, walnut, and other expensive "cabinet" woods. This may mean, in effect, that the discovery has suddenly increased manyfold the forest resources of the country.

Versatile melamine

Another promising new plastic made its bow in 1940 under the sponsorship of the American Cyanamid Company. It is based on melamine, a long neglected chemical Cinderella rescued from the ashes by Cyanamid's big research staff. In 1938 there was only a small quantity of melamine in existence, and if for some odd reason you wanted a pound of it, the price would have been $40. Chemists had a hunch that this laboratory curiosity could be put to work, and they procured a small quantity of the white, crystalline powder and put it through an exhaustive grilling. They learned how to make it cheaply from coal and limestone, and found that you could heat the powder to 670 degrees Fahrenheit before it would melt. They combined it with formaldehyde and produced a tough, hard material that will duplicate the performance of several other plastics and has a few special virtues of its own. Melamine soon sold by the carload for forty cents a pound. The plastic is used to make dishes and drinking glasses, and to make a new, inexpensive, scratch-proof lacquer for automobiles and refrigerators. A velvet dress treated with this material may be rumpled and crushed, and the fabric will quickly regain its shape with no creases. A paper towel treated with melamine resin does not lose its strength when it is dampened, although its ability to absorb water is not affected.

Perpetual trouser-creases

The use of melamine and other resins in the treatment of wearing apparel is an important field by itself. The Monsanto Chemical Company has recently announced a method of treating wool so that the fabric will not shrink, its wearing qualities will be doubled, it will not shine, trousers and suits that are once pressed will hold their creases even in a rain, and garments will not wrinkle when packed in a suitcase. It is possible that the man of tomorrow, his garments "plasticized" all the way from straw hat to shoes, will walk through a downpour without needing a change. And his wife may benefit by the new plastic resin treatment of fur invented by Jose B. Calva of St. Paul, Minn. By this method, various resins, including phenol-formaldehyde and urea-formaldehyde, are used to give inexpensive furs like sheepskin the appearance of luxury furs. There is a chemical reaction between the fur and the resin, so that the resultant material has the properties of a plastic rather than those of a fur. For this reason, the new material is mothproof, and is said to wear many times longer than untreated fur.

Many other new developments are under way in the manufacture of nylon, rayon, other synthetic fabrics which, like fountain pens and bomber noses, are made from plastic resins.

Plastics in the Army

Plastics have played an important wartime role in improving the equipment of the individual soldier. The old steel helmet, for instance, had its shortcomings. It was so heavy that men got stiff necks from wearing it as a rain hat in safe areas. The rivets which fastened it to the head harness were driven into the skull if hit by flying metal. So an inner helmet of fabric-reinforced plastic was designed for the soldier to wear in camps and base towns. The new rivetless steel helmet fits snugly over the plastic liner, and since it now has no head harness, it can be used as a wash basin or water bucket, or for bailing a boat. We entered the war with the aluminum canteen adopted in 1910, but all of the white metal was needed for planes. A featherweight canteen of ethyl cellulose plastic was adopted. The new canteen is so strong that a man can jump on it; it emits no metallic clank to betray the owner's position, and since the plastic is a poor heat conductor, it doesn't burn a man's hands when filled with hot coffee. Plastic bugles wake men up melodiously and need no polishing; olive-drab plastic uniform buttons also save polishing time and do not glint in the sunlight. There are plastic riflestocks to take the place of scarce walnut, and pliable transparent plastic bags of Vinylite film for floating the rifle across a river. The waterproof bag is slipped over the rifle, or other piece of equipment, and a knot is tied in the end. Sufficient air is entrapped to provide buoyancy, and the soldier pushes the rifle ahead of him while swimming or wading in deep water. If he needs his rifle quickly on the opposite bank, he can shoot through the bag. Other plastic bags are sealed around airplane motors to protect them from rust during shipment, and chemical pellets inside the bag absorb whatever moisture remains in the enclosed air. This takes the place of the coating of grease which must be washed away before the motor can be used. Then there are the five-gallon metal water cans used in the field. Soldiers put lemonade in them and got sick. A lining of plastic resin made them safe for any beverage.

The use of color in a plastic is not always for display. Before night flights, airmen wear red-tinted plastic goggles to prepare their eyes for darkness. Pilots in training can "fly blind" in the daytime by wearing these red goggles, while the windshield and other apertures are covered with green-tinted plastic sheets. The pilot sees his instruments, but cannot see outside the cabin. But the instructor, who wears no goggles, sees through the windshield easily and can warn his charge of danger.

Magic glue

Versatile is the word for plastics, and another of their myriad jobs is the sticking of various materials together. As mentioned above, the bonded plywood boats and planes could not be built without strong, weatherproof synthetic resins. Now there is a promising new resin which will bond not only wood, but all manner of materials in an unbreakable union. It will unite metal to metal, or to wood, plastics, glass, fiber board, natural rubber and most synthetics. Cycleweld is the name of this universal glue. Its chemical composition has not been revealed. It was developed by S. Gordon Saunders of the Chrysler Corporation. Mr. Saunders, an expert on paint and synthetic resins, got started on the project when someone asked at a technical conference, "What makes paint stick to metal?" It occurred to him that it would take tremendous power to pull off a single square inch of paint on the surface of an automobile. Here was a super-strong "one-way" adhesive—an equally powerful adhesive that would work both ways would be of great value. Armed with this rough idea, Saunders worked for five years, finally perfecting his glue.

Cycleweld is now being used to supplant rivets in building airplanes. Metal wing flaps for a certain fighter plane are glued together in eighteen minutes, saving hours of riveting time. Once it took 1,200 rivets to hold in place the interior supports of the wing flap. Now the synthetic adhesive is applied with a spray gun, and the assembled flap is squeezed together in a heated press, eliminating 900 rivets and cutting the cost by one-third.

New horizons in housing are also in sight because of this process, which makes possible the permanent gluing of all manner of building materials. Floor panels for prefabricated houses have been made by Cyclewelding sheets of corrugated steel within thin layers of plywood. About as thick as ordinary flooring, it is much lighter, and so rigid that only half the normal number of joists are needed. The glue has also been used experimentally in assembling light-weight plywood furniture, eliminating the heavy corner posts necessary to anchor screws. When you find a glue that will stick almost anything to anything else, the possibilities are immense.

Giant toothpaste tube

Another Chrysler engineer, Walter P. Cousino, has invented a continuous plastic extruding machine that could turn out a two-inch pipe long enough to reach from coast to coast if you gave it enough raw materials and forgot to stop it. Six years ago, Cousino, a farm boy turned mechanic and amateur inventor, decided to investigate plastics. Anyone with a little capital can go into the plastics molding business, and with $100 Cousino bought spare parts to build his first molding machine. He and his wife spent evenings in the basement making plastic fish and deer eyes for taxidermists, and with the same machine molding rubber tires for miniature automobiles.

In Cousino's first extrusion machine, he used a piston to force the hot, wet plastic through the shaping die of the "toothpaste tube." Later he added a worm screw to provide continuous operation. Soon his firm made him a project engineer, and his basic ideas were used in the new injection-molding and extruding machine. By means of a simple adjustment, the same machine will turn out a procession of molded plastic articles, or an endless rod or pipe, which is automatically cut in convenient lengths and carried away on a conveyor belt. These tubes of thermosetting plastic are highly resistant to corrosion, according to the manufacturers, and can be used for overhead or underground pipe lines. One of the machines has been used to make rocket-launching tubes for the undersides of airplanes.

The extrusion method of producing plastic materials in a continuous flow may have a spectacular future. It is reported that the Germans have been squeezing out continuous plastic boards for structural use. If this is true, it seems safe to assume that Cousino and his colleagues need not lag behind.

Coffee plastic?

Thousands of research men are working on plastics, and new ones are being announced constantly. Caffelite, a plastic made from coffee, may have an interesting future. Brazilian planters hope that it will provide a market for great quantities of low-grade coffee which is often a drug on the market. At a pilot plant at São Paulo, Brazil, plastic sheets which can be drilled, machined and polished have been made in many colors, and the makers predict that the cost will be low enough to permit wide use for flooring, wallboard and other building purposes.

Wasted treasure

Lignin, one of the principal components of wood, which is removed from the wood pulp and thrown away in the manufacture of paper, is hailed as another great source of cheap plastics. For many years, vast quantities of lignin waste have been poured into streams, where they poison the fish. Then chemists of the U. S. Forest Products Laboratory at Madison, Wis., began to investigate uses of lignin and concluded that the paper industry was junking a chemical treasure house. After many years of research, the Marathon Paper Company of Rothschild, Wis., began recently to convert the resinous stuff into a number of valuable products, among them, plastics. Molding powders are made from which small objects are pressed, and lignin plastic resin is used with paper and cloth to make light, strong, laminated sheets for many purposes. So far, reclamation of the constantly flowing lignin waste is only a drop in the bucket. Chemists must learn more about lignin. Some experts believe that when studies now in progress have been completed, reclaimed lignin will double the easily available supply of plastics raw material, and will furnish the cheapest general-purpose plastic on the market.

Enter "silicones"

The industry is currently excited by the arrival of a whole new family of plastics based on the element silicon, which occurs abundantly in the earth's surface and is the basis of glass manufacture. Most plastics, based upon carbon, will stand up under the heat they are likely to be subjected to, but the fact that the new "silicones," as they are called, will stand far higher temperatures, have made them of immediate importance in electric insulation.

Every new plastic does unexpected things, and when Westinghouse engineers redesigned a three-horsepower electric motor and used silicones for insulation, the output of the motor increased to ten horsepower. This result was too good to be typical, but tests on other motors indicate that the new plastic's heat resistance will soon lead to lighter and better electric motors. Dramatic results in other uses of silicones may be expected. The Dow Corning Corporation and the General

Electric Company are making the silicone products in both solid and liquid form for many purposes. While a number of war uses are still secret, it has been revealed that General Electric is using a rubber-like silicone material to make gaskets for B-29 turbosuperchargers, which operate at very high temperatures, and to support the lenses in large Navy searchlights, which must withstand severe heat from electric carbon arcs.

At a recent demonstration, chunks of General Electric's rubber-like silicone plastic were distributed which are as soft as putty, but which bounce like a lively rubber ball. Since this material can be made to hold its shape by vulcanization, plans are under way for postwar golf and squash balls, and it has even been suggested that tires may sometime be made from it.

Another promising new development is the combination of a thermosetting resin with fiberglas (a thin fiber made by directing a jet of air against a stream of molten glass) to produce light, strong structural parts. This plastic-glass combination is being used to make the cabin framework for the new war helicopter R-6. It is only half as heavy as aluminum, and is strong enough to stand up under heavy punishment.

There is no doubt that further revolutions will be wrought in many machines, processes and commodities by plastics now in use or yet to be developed. Many of these changes, as in the insulation of an electric motor, will take place where people cannot see them, but can only judge by the results. It is extremely unlikely that consumers' dreams about cheap, mass-produced all-plastic automobiles, planes, houses and boats will be realized. You can make almost anything out of a plastic if you can pay the price, but compared with most common structural materials, plastics are very expensive. Wood, steel, iron, brick, cement and glass are all dirt-cheap compared with the least expensive plastic, and where these materials will do about as well, the use of a plastic would be folly.

Plastics will be used only where their special qualities will earn back their high initial cost. Such practical uses are legion, for their virtues are many and varied. The new technical developments of the next decade will be a fascinating spectacle, and the performance of plastics will be one of its stellar acts.

CHAPTER THIRTEEN

STAMPED FROM METAL DUST

In a few deceptively small plants scattered throughout the Northeastern industrial area, machines are fashioning metal objects of many sizes and shapes by a curious new method. They are stamping them out of powder and baking them. By this process, they are making machine tools so hard and durable that tempered steel seems soft by comparison. They are making tungsten wire finer than human hair—a delicate job which can be done by no other method. They are manufacturing porous, self-lubricating bearings that are used by the million in tanks, planes, automobiles, refrigerators and washing machines. They are making new and better products by combining metals that could never be joined before. And all this is done at a tremendous saving in materials and man-hours.

These things have to be seen to be believed. In a Detroit plant where cylindrical bronze bearings are manufactured, you may see on the metal table of a stamping machine a pile of drab dust which looks about as fine as face powder. This powder has been carefully mixed by recipe. A mechanical arm rhythmically pushes the powder into a hole in the center of the table, filling a mold of the desired shape. Then a ram descends with a force of many tons, and compresses the powder into a cake, or briquette. Every few seconds this operation is repeated, and the newly formed bearings are carried away on a conveyor belt.

These "green briquettes," as they are called, have the trim, shining and firm appearance of freshly minted coins, but they are so fragile that you can crumble them between your fingers. After they are carried by an endless belt through the "sintering furnace," which bakes them like a batch of cookies, they are so hard you can dash them against a brick wall or jump on them without breaking them. In less than half an hour, the formless dust, so fine that a hearty sneeze would blow it away, has been converted into a solid bearing in the exact dimensions needed, ready for the most gruelling service.

This is only one example of the great progress of recent years in metallurgy—an art upon which all other mechanical arts depend. The history of metal-working processes parallels the story of man's material advance. Men may invent engines, helicopters, electron tubes, plastics, or new fuels, but without the talent of the metallurgist, all these things would remain sterile concepts, condemned forever to the prison of the mind.

Metals, it was stated in the previous chapter, may be described, broadly speaking, as plastic materials. By means of pressure, heat, or both, metals in fluid form are converted into simple objects for the consumer, into tools for making articles from metals or other materials, and into the millions of variegated machines which take the place of human sinews. Most of these products are made by melting the metals and casting them in the shape needed, by carving them in various ways from pre-formed blocks or by some combination of the two methods.

There have been tremendous improvements in these older ways of forming metal objects. Modern guns, motors, automobiles and airplanes are all built upon these improvements. But these methods have their limitations. By reducing the raw materials to freely-flowing powder instead of melting them, many of these limitations have been overcome, and triumphs of fabrication unheard of a few years ago have been achieved.

Powder metallurgy is not new, but its development since the war started is a mechanical miracle. There is a complicated unit of an anti-aircraft gun mount, for instance, a part of many facets and angles, which once was a machinist's nightmare. The part was needed in great quantities, and it took two hours of skilled labor to shape it by conventional methods from a blank piece of metal. The Amplex Division of the Chrysler Corporation in Detroit, which is that firm's powdered metals section, took over the job and made a die for pressing the part from powder. Soon the parts were streaming forth from the sintering furnace at the rate of one every four or five seconds. The method was used to produce many other small parts in the gun mount (a "mount" includes everything but the barrel) with the result that 240 man-hours were saved for every gun made.

Bearings that oil themselves

Time-saving is only one reason for stamping objects out of metal powder instead of cutting them from solid stock. Machine parts that can be produced in no other way are pressed from powder, and one of the most spectacular of these is the self-lubricating bearing that sucks up oil as a sponge absorbs water, and gradually doles it out during a lifetime that is often longer than that of the machine it serves. These bearings are pressed from copper, tin and solid lubricants, and may be made more porous by adding to the mixture a volatile which evaporates during the heat treatment. This leaves an invisible network of tiny reservoirs which holds oil up to thirty-five per cent of the volume of the part.

If you take one of these small cylinders and squeeze it slightly in a vise, tiny drops of oil exude from its pores. Release the pressure and the oil is sucked up again. This shows what happens to a self-lubricating bearing in action, when installed in a tank, an automobile, or another piece of machinery. The greater the strain, the more generous the lubrication supplied by the bearing, and when the strain is over, the oil is reabsorbed by the sponge-like cylinder and awaits the next call to work. Some of the tank bearings have been run under test for a billion revolutions with no appreciable loss of oil.

Self-oiling bearings allow gun crews to forget many "lubrication points" and concentrate on the enemy. In sub-zero climates where "free oil" freezes, the oil in these bearings is not affected, nor do they "bleed" their oil in tropical heat. Time is saved not only in factories, but on fighting fronts, where delay is fatal.

Long before the war, the self-lubricating parts were silently doing their work in automobiles, washing machines, mechanical refrigerators and farm machinery. Early in the twenties, Moraine Products, a General Motors subsidiary; the Bound Brook Oil-less Bearing Company, of New Jersey; and later Amplex and other firms, began making self-oiling bronze bearings for automobile starters, clutches and water pumps. Running on bearings which are actually one-third oil, washers and generators are sealed up, and lubrication is forgotten during the life of the machine. In cases where the oil in the bearing is likely to be exhausted before the machine wears out, additional oil can be installed in a sealed cavity adjacent to the bearing, which will absorb it as it is needed. Self-oiling, squeakless hinges followed, and Chrysler adopted a porous striker plate for automobile door latches which was cheaper and stronger than its predecessor, and ended the annoyance of oil-spots on clothes.

Virtually all our war machines have been doing a better job because of the pressed-powder parts. The terrific strain when a plane flattens out at the bottom of a power dive has sometimes ruptured the pilot's diaphragm, and the strain threatens the machine as well as the man. Details are secret, but a self-lubricating bearing pressed from powder protects some of the faster fighting planes from damage by these instantaneous loads of enormous pressure.

Patch's coffeepot

The porous metals have a number of uses other than lubrication. Earl Patch of General Motors, who was one of the pioneers in the introduction of porous bearings, brought his coffeepot to the plant one day and suggested to research men that since they made porous metals from powder they should be able to make a coffee filter. They set to work. Out of the sintering furnace came a disk of coarse, bright-colored sand that would not crumble. It was a failure, for eventually the coffee grounds filled the pores and became rancid. But the work was not wasted. At the same time, the firm's Diesel engine division was looking for a filter for fuel oil to keep the tiny holes in the injector from clogging. Patch's coffee filter was ideal for the purpose. It was adopted, and has been used in tank, submarine and truck Diesels.

It occurred to the National Cash Register Company that if a piece of porous metal will absorb oil, it will also hold ink, so they built an experimental model of a ribbonless typewriter in which the type is made of extra-porous bronze. It is reported that the type will hold enough ink to write several hundred thousand words before re-inking is necessary.

Another composite metal made from powder is used to provide friction for clutch plates and brake linings. Powdered bronze, graphite and silica, evenly distributed, are pressed and baked to form the flat slabs. When the brake is applied in a tank or bomber landing wheel, the graphite powders away at the surface, and the silica particles provide excellent friction. The braking requirements of the big bombers are tremendous, and the powdered metal linings meet the test better than any material formerly used.

These are a few of the newer uses of articles stamped from metal dust. In other applications, powder metallurgy has changed the course of entire industries and literally affected the fate of civilization.

The Egyptians thought of it

Historians of the artifice trace its origin to Egypt at about 3,000 years before Christ. These ancients left iron implements behind them.

This was long before the development of furnaces suitable for melting iron ore; furthermore, microscopic examination of the implements indicates that the iron was never melted. So it is assumed that the Egyptians heated and compressed particles of sponge iron into slabs, and beat them into useful tools while the metal was still hot. This was the crude beginning of powder metallurgy.

Nothing more was done about it until the early 1800's, when the noted English chemist, William Wollaston, became interested in platinum. The melting point of this precious metal is 3,225° F., and there were no furnaces hot enough to make it flow. Centuries before, Ecuadorian artisans had used easily melting gold and silver to bind particles of platinum in articles of jewelry. Wollaston was determined to make platinum workable, and he succeeded. He kept the process secret during his lifetime, and is said to have made a fortune from it. In a paper published after his death, his method was revealed. He had reduced the platinum to powder by chemical means, and by repeatedly pressing and baking it, had converted it into solid form of the shape desired.

Better electric lamps

After this revelation, powder metallurgy went to sleep for another century. Then came Edison and the incandescent electric lamp. The first lamps were shortlived and gave comparatively little illumination for the power used because of the great difficulty of finding a suitable material for the filament. The early carbon filaments were improved, then came the more efficient filaments of hard, brittle tantalum. But the lamps with tantalum wires were suitable only for direct current circuits. When used with alternating current, they burned out rapidly because the tantalum crystallized. Edison knew that the best material of all would be the even more hard, brittle and unworkable tungsten. If only tungsten could be made into wire, lamps would give far more light, use less power and last longer. In short, the new electrical illumination industry would acquire tremendous impetus.

Tungsten melts at 6,100° F. No furnaces existed hot enough to melt the intractable stuff so that it could be worked like ordinary metals. Even if there had been such furnaces, they would not have solved the problem, for we now know that when tungsten is melted, big crystals are formed which reduce its practical value. In its natural state, tungsten does not even stick together in a lump like ordinary metals. It exists only as a fine powder or as a mass of partially united particles.

This was the state of our knowledge of tungsten when word came from Germany that someone had actually made a lamp filament from the exasperating metal. Dr. Willis Whitney and John W. Howell of the General Electric Company were sent on a sleuthing expedition to Berlin. Soon after their arrival, they were walking along a street one evening and saw a shop window lighted by electric lamps of dazzling brilliance. After an interview with the shopkeeper, they were hot on the trail. They found that tungsten filaments had been first made and patented by a penniless Viennese laboratory worker named Dr. Alexander Just. He and his partner, Franz Hanaman, had made a sticky paste from powdered tungsten, sugar and gum arabic, had squirted it through a fine nozzle, wound the wet filament on cardboard as it emerged, and then subjected it to a treatment involving heat. Intense heat was needed, but not nearly enough to melt the tungsten. This eliminated the temporary adhesive, and by a kind of action which is still a subject of debate among technical men, sintered, or joined together the tiny particles of tungsten to form a filament. The General Electric Company paid Just and Hanaman $400,000 for the rights to their patent, made deals with two German inventors who had made counter claims, and in 1907 placed the tungsten filament lamp on the market. It was an immediate success, for it gave twice as much light for the power consumed as the most efficient lamp previously made.

But this filament made of specks of tungsten dust glued together was extremely brittle and fragile. William D. Coolidge, famous researcher of the Schenectady firm, announced his belief that tungsten could be made ductile, or capable of being drawn out from a solid bar into a thin wire. Coolidge struggled for six years with his self-appointed problem, and finally solved it. In a complicated process of many operations, Coolidge pressed the tungsten dust into a briquette which would disintegrate at the touch of a finger, gave it a preliminary baking, then ran an electric current through it to give it another sintering treatment just below the melting point of the metal. Then he heated it white-hot and put it through a "swaging" or mechanical hammering machine which hit it 10,000 times a minute and beat it into a thin rod. Finally he drew it through a tiny hole in a diamond to make strong, pliable wire one-sixth the size of a human hair. Dr. Coolidge's tungsten filament has since been used in all incandescent lamps. Its increased efficiency has saved the world billions of dollars, and has contributed immeasurably to the widespread use of electric illumination. This was powder metallurgy's first great triumph.

Cutting tools for war

Another use of the new art has had world-shaking results. This is the tungsten-carbide cutting tool, the hardest known machine-making instrument, which keeps its edge when it is red-hot, and because it outwears any other metal-working tool manyfold, increases the rate of production of guns, projectiles and other war essentials. The Germans invented this powerful industrial weapon. Germany's full employment of it is considered an important factor in her rapid preparation for World War II, and her ability to continue war production long after "experts" had predicted that she would have shot her bolt. The great military importance of these tools was demonstrated when the American Department of State finally persuaded the Franco government to reduce the export to the Nazis of wolframite, the chief tungsten-bearing ore, which abounds in the northwestern part of Spain. The tungsten-carbide tools also became a subject of controversy a few months after Pearl Harbor, when it became clear that the German war plants were making much wider use of the super-hard tools than plants in the United States. At that time the anti-trust division of the Department of Justice charged that the General Electric Company, whose subsidiary, the Carboloy Corporation, years ago began to make the tools under license from Krupp, had restricted American production of the tools, to the ultimate detriment of the war effort. To this the firm replied that their foresight in securing the patents had proved to be of great benefit in equipping our war plants.

Since then, production of the tools by a number of American firms has expanded tremendously, and whatever may have been the reasons for our slow start, the tools pressed from powder are now working miracles in hundreds of big factories. There are many recipes for shaping the tungsten powder into an edge which cuts through steel like a knife through cheese. Tungsten carbide may be mixed with cobalt, which melts at 2,939° F. compared with tungsten's 6,100° F. melting point. The heat of the sintering oven melts the cobalt, which forms a film over the sharp, hard cutting-crystals.

These long-wearing tools are made in all shapes and sizes. There are small drill-tips which sell for less than $2.00, and big dies which cost several thousands. They are also made in the form of cutters for use on lathes, and as razor-edged abrasive disks which, when rotated at high speed, slice through armament steel. Diamond dust is sometimes united with powdered copper to make these cutting wheels.

The time and labor saved by such tools is impressive. An engineer reports that in one operation, cutting tools of high-speed steel wore out in six hours, while the tungsten-carbide-tipped tools that replaced them were good for ninety days. Industry looks forward to a day when not only big factories, but small machine shops and repair shops throughout the land will be equipped with tungsten-carbide tools, bringing about great economies.

Other uses are suggested by a tungsten-carbide phonograph needle recently put on the market. The same hardness that creates superb metal-cutting tools enables the needle to play a thousand or more records without dulling its point. Dental tools from metal powders are also being perfected.

Marriage of convenience

Metals that ordinarily will not work together, and cannot be combined by any other method, join willingly when pressed together in powdered form and routed through the sintering oven. This makes it possible to combine metals which have special virtues and thus create a "pseudo-alloy" which possesses the best features of each. For instance, copper is one of the best known conductors of electricity, but it melts at a fairly low temperature. Tungsten is not a good conductor, but it resists intense heat. Obviously, a marriage would be highly convenient, but engineers knew that if they tried to merge the two metals with heat the copper would completely evaporate before the tungsten reached its melting point. When both metals were reduced to powder, they were united easily by the new method, and now the electrical industry has a metal which is an excellent conductor and also withstands the heat of an electric arc when used in a circuit-breaking switch or welding electrode.

The powder process is also useful in manufacturing metal parts so small that they are difficult and expensive to produce by older methods. Millions of tiny magnets for use in the electrical equipment of airplanes have been pressed from powder as fast as so many buttons. They are cheaper and quicker to make than cast magnets and because of their fine grain are more resistant to shock. Fine copper screening for use as laboratory filters is now made from metal powders. The screening is stamped out in a die and hardened in an oven by a method much the same as that used in making gears and bearings. This is faster than weaving the screens from wire, and since all the joints are welded together, the screen cannot ravel and the meshes are held to their original dimensions, thus assuring greater accuracy. These screens are used, for example, to test the fineness of the particles in various powdered metals, since the size of the dust specks has a great deal to do with the durability of the finished parts.

Twenty-eight different metals are now being produced in powdered form and used in various combinations to produce tens of thousands of different products, but experts say that this is only a beginning. Virtually all metals can be powdered and united with others to create new materials for a wide variety of uses. Gold, platinum and silver, for instance, can be powdered and processed with harder metals to mass-produce novel and durable ornamental objects which would need little or no finishing after they leave the sintering oven. Table silver and jewelry have been suggested.

Powder metallurgy has a brilliant future if we consider only the products which can be made in no other way, like self-oiling bearings and tungsten-carbide tools, and complicated parts like gear wheels in which the elimination of costly machining pays big dividends. Some engineers look beyond these uses and predict that with lowered costs of metal powders the process will compete more and more with casting and forging, and that all manner of simple metal objects will be pressed from powder and baked like cookies.

How the powders are made

Because the raw materials of the process must first be reduced to powder, they cost more than solid metals. Powdered copper, for instance, may cost eight cents a pound more than solid copper. A variety of methods are used to make the powder, which is manufactured by a number of firms and shipped to the fabricators. Metals with low melting points, like lead, tin, aluminum and zinc, may be made into powder by atomizing a stream of the molten metal with an air jet. Copper, iron, or nickel powders can be made electrolytically. By the use of large currents, they are deposited in a spongy mass on the electrode, and the mass is scraped off and easily pulverized. Some powders may be made by chemical methods. Iron powder is made directly from ore without smelting. It is ground fine in a ball mill, reduced to iron oxide in a furnace, then treated with hydrogen to produce the pure iron powder. Before the war, processors depended on high-grade iron ore from Sweden. Since that supply was cut off, methods have been developed to produce the powder from domestic ore and iron and steel scrap at comparable cost.

There are a number of extra savings which help to offset the added cost of making the powder. By other shaping methods, fifty to seventy-five per cent of the solid metal is often scrapped in the form of chips and shavings. When parts are pressed from powder, nothing is wasted. Less factory space is needed, since the forming die does the work of half a dozen bulky machine tools. Fewer men are needed, and because the process is largely automatic, many of them can be semi-skilled.

The size of the articles which may be pressed from powder has greatly increased because of experience in war manufacture. Only a few years ago, production was limited for the most part to small symmetrical articles weighing only a few ounces. Now Amplex is stamping out powdered metal tank bearings weighing fifty-seven pounds, and ways have been found to make many complicated parts with irregular protuberances. Yet the process has its limitations in this respect, and probably always will have. In making the briquettes, the powder must be uniformly pressed perpendicularly or horizontally; the process will never approach plastics in the variety of shapes obtainable. With these limitations in mind, it is still possible, as one enthusiast predicted, that metal powders will sometime be pressed into everything from a watch part to a locomotive wheel.

The mystery of sintering

Every cent of reduction in the price of metal powders opens the door to new uses, and further scientific research is expected to improve the process. Prof. John Wulff of the Massachusetts Institute of Technology is a leader in this investigation, and Prof. Gregory J. Comstock of the Stevens Institute of Technology conducts a metal powder laboratory sponsored by a number of large corporations. Prof. Comstock is trying to discover, among other things, exactly why the oven's heat turns the fragile briquettes into hard metal parts. For "sintering" is still something of a scientific mystery. In many products made of metal powders, including the porous bearings, the welding electrodes and the cemented tungsten-carbide tools, the union seems easy to explain. The temperature of the sintering oven is higher than the melting point of one of the metal powders in the recipe, and it melts and hardens, locking the non-melting ingredient in place.

But in other products, including the tungsten lamp filaments and articles made wholly from powdered iron, aluminum or brass, nothing melts, and there must be a completely different explanation of the union of the particles in a solid mass. Prof. Comstock has suggested that as a result of pressure and heat the surface atoms of the tiny specks of metal dust form an interlocking embrace with surface atoms of adjacent specks, and that this behavior rapidly spreads throughout the part being fabricated in a kind of progressive chain reaction not unlike that of a closing zipper. Such tentative theories are far from being purely academic. While manufacturers are rapidly expanding production on the basis of present knowledge, a complete understanding of the scientific principles involved might have a profound effect upon processes of fabrication.

Better engines from powder?

Every new development in metal fabrication is like the pebble tossed into the pool—the ripples travel far. Readers will recall that increase of the efficiency of the gas turbine depends upon the manufacture of turbine blades which will stand up under hotter and hotter blasts of burning gas. But as we have seen in the case of tungsten, it is difficult to work metals which will hold their shape under high temperatures. Is the answer to be found in turbines pressed from powder? This possibility is being investigated, and engineers are not unanimous, but one may speculate on the possible effects on our everyday life of lighter and more powerful kerosene-burning gas turbines, perhaps to supplant present engines in busses, trucks and even passenger cars.

Long before such a motor is perfected, parts pressed from metal dust may greatly improve our internal combustion engines. Dr. Paul Schwarzkopf, Austrian pioneer in the field who is now director of research for the American Electro Metal Corporation of Yonkers, foresees a day when powdered metal will be pressed to make super-hard inner jackets for plane and automobile engines, prolonging their life indefinitely and adding greatly to their power.

Other metallurgists are compiling their lists of new uses. Many of them predict that powder will revolutionize the metal industry, which would mean changes incalculable in the living habits of the mechanized world.

CHAPTER FOURTEEN

CLIMATE A LA CARTE

In the motion-picture version of H. G. Wells' ambitious trek into the future, *The Shape of Things to Come,* all men were noble, handsome and healthy creatures whose cities were stately, air-conditioned domes protected against the brash vicissitudes of natural weather. Tales of the old, squalid days of sneezes and coughs and sweltering heat were told to instruct the young, and man, relieved of his semiannual burden of adjustment to the sun's declension, took a hitch in his belt and set out to conquer the universe.

Like most of the visions of Mr. Wells—who might be called the patron saint of industrial designers and advertising artists—this concept of freedom from weather's caprices had much of value behind its fantastic façade. Already his prophetic title is beginning to justify itself. Since audiences saw his film in air-conditioned comfort that summer of 1936, indoor weather-control has come to occupy an increasingly large place in our daily lives. Already, with our quick and casual acceptance of improvements which scientists and engineers labored half a century to bring to us, we are beginning to demand air conditioning as a natural right, not only in theatres and auditoriums, but in restaurants, department stores and hotels, and its occasional failure on war-burdened passenger coaches is the signal for groans of complaint.

Yet air conditioning, strongly associated as it is in the public mind with compartments of assembly or travel, means far more than human comfort. Towns where not a single building has summer cooling are now reaping benefits from controlled weather in the form of fresher foods and better manufactured products, and more benefits are on the way. For air conditioning has become, among other things, an indispensable machine tool. Like most machine tools, it has been called to the colors, and there is hardly a critical operation in war production that is not being done faster, better or cheaper because of it.

Soon after war production got under way, the officials of an Eastern war plant where certain essential high-precision instruments are made for the Navy were greatly disturbed by the number of rejections. The delicate instruments were rigidly inspected before they left the plant, and the makers would have sworn that they were in flawless condition. But after a few weeks or months, tiny specks of corrosion would appear on their highly polished surfaces. This made them useless for the purpose intended. Naval officers proved to their satisfaction that the valuable equipment had been kept clean and dry, and stated as their opinion that the mystifying failures must be blamed on the manufacturer.

The "saboteur" was finally identified. If in the process of assembly a damp fingertip so much as brushed one of the mirror-like areas, the acid in the perspiration planted the invisible germ of future deterioration. Perspiration did not have to run freely—the merest trace of bodily moisture did the damage. Looking further into the matter, engineers found that while dampness from healthy persons was bad enough, perspiration from workers with colds or other acute disorders were sure poison.

Machine-made weather was the answer. Air-conditioning equipment, to control temperature, relative humidity and air circulation, was installed in the room where the instruments were assembled, so that even on broiling summer days the fingers of the workers were dry. Rejections fell to almost zero, and another link was forged in the endless chain of Allied war production.

Before the smoke from Pearl Harbor had cleared away, plans were made for vast new acres of drafting rooms, where at miles of tables an army of engineers would do the necessary paper work to start bombers, tanks and guns upon their way. It is a fact that a blueprint six feet long, drawn in the cool of the evening, may expand by as much as an inch in the heat of the day, which may easily lead to a serious error in construction. And once there was an annual loss of thousands of man-hours due to the accidental smearing of blueprints by sweating hands. Now all the war-plant drafting rooms are supplied with dustless, uniform artificial weather. Because of fewer ruined prints and the greater comfort of the draftsmen, summertime production in this vital first stage has been stepped up by as much as forty per cent.

"Freezing" dimensions

One reason for the great improvements made in our warplanes and weapons is the closer fit, or "finer tolerances" of the various parts. Today's tolerances often run to plus or minus a ten-thousandth of an inch, which is about thirty per cent finer than those of only five years ago. This has raised problems in mass production. A part made in the cool of the night and assembled in the heat of the day may expand more than the allowed tolerance, and so may have to be rejected. Or a part made in St. Louis may not fit a companion part produced in the cooler climate of Springfield, Mass. Air conditioning removes these inequalities, "freezing" dimensions during manufacture. All delicately fitting parts are now made in the same artificially controlled climate, so that no matter when or where a part is made, it fits when it reaches an assembly plant which may be a thousand miles away, or when it is used to repair a stricken plane in a distant battle zone. Tailored weather now makes it possible to produce all manner of delicate instruments by mass-production methods, for it imposes standard conditions under which workers trained for a few weeks can do as well as those who have long apprenticeship. Without this uniform atmosphere, production of the famous Norden bomb sight, for instance, would be cut drastically during the summer months.

The highly polished gauge blocks, finely divided calipers, and other super-critical measuring devices used by every production plant to check the accuracy of tools are themselves prey to variations due to contraction and expansion of their metal with changes of natural weather. Experts say that if the temperature of the test room varies by as much as one degree, they can detect a difference in these "yard-sticks." Again, air conditioning prevents error. With test rooms kept constantly at specified temperature and relative humidity, these final arbiters never lie.

Air, which most of us take for granted as a standard substance, is not simply air. It is cold or hot, moist or dry, clean or dusty, dense or thin, odorless or unpleasant, quiet or in motion. Prepared according to various recipes, it is doing a thousand new jobs in the production of wartime materials, weapons, tools, foods and medicines. Conditioned air is indispensable in the manufacture of synthetic rubber, high-octane gasoline and plastics—chemical processes which demand close temperature control. In the great testing laboratories it can be made to simulate any climate or altitude, and of most importance to the factory worker or serviceman, it is increasing human comfort and efficiency all the way from the war plant to the fighting front.

The vast, dust-free windowless plants from which pours the unending river of invasion-bound war goods would have to shut down tomorrow if they were ventilated with air-as-you-find-it. The greater the technological advances in manufacture, the greater the number of machines assembled in a given space. Every machine generates heat by friction; the bulbs and tubes which illuminate the plant add more heat, and every worker constantly gives off as much heat as normally comes from a 100-watt light bulb. In many of these plants, the temperature would be 100 degrees or more if industry had to depend upon natural atmosphere. The vitiated hot air must be continually pumped out and replaced with an even supply of cooled, filtered, made-to-order air.

More than four billion dollars' worth of electronic equipment—the heart of radio, radar, and other vitally important war devices—were scheduled for manufacture in American plants in 1944. This job simply could not be done in plants supplied with untreated air. Electronic tubes, like light bulbs, are highly efficient furnaces, as you can tell by placing your hand inside your receiving set, and if the heated atmosphere were not continuously exchanged for artificially cooled air, any room where a large number of these tubes are made, tested or used, would quickly become a Turkish bath. Dryness and immaculate cleanliness of air are equally important. These facts were not clearly understood when the electronics industry embarked upon its skyrocket expansion with the coming of war, and in one plant which relied upon natural air, the rejection of faulty tubes ran as high as eighty per cent. Now, processed air is a must.

Without modern air conditioning the war's great demands upon the copper mines could hardly have been met. Once, when new low levels were opened, where temperatures run as high as 150 degrees, it was standard practice to blow air through the tunnels for three years or so until they were cool enough to work in. Now mechanical refrigeration cools off these sweltering holes in less than a month, and in one of the country's most productive copper mines the thermometer is kept at ninety degrees, at a level 4,600 feet underground.

Front-line comfort

On the fighting fronts, both on land and sea, air conditioning follows the heat-radiating electronic tube. The communication compartments in which the tubes are used are sometimes sealed chambers thickly walled against gunfire and outside disturbances. A supply of cooled, filtered air makes it possible for human beings to live and work in these chambers. The roofs of military radio trucks on the Pacific islands and in Africa are often heated by the sun to 160 degrees or so, and inside there is often enough warmth from tube radiation to heat a small house. No one could exist long under those conditions without air conditioning. For this use, special built-in equipment was designed.

"Packaged weather" on wheels has a number of important war uses. During the fighting in torrid North Africa, an air-conditioned motor caravan, the first of its kind in existence, enabled a flying squadron of engineers and technicians to eat, sleep and do their paper work in cool comfort, while the thermometer outside registered about 130 degrees. The trailer bunkhouse has twenty-four built-in cots, with room for six hammocks in the aisle, and has its own lavatory and shower bath. Another trailer holds an air-conditioned kitchen, complete with stove, utensils and refrigerator, in which meals can be prepared for as many as 300 men, and the third trailer is an ample refrigerator for food storage. Engineers used the caravan in constructing advance bases for troops.

By means of similar portable refrigeration units, meats and vegetables frozen in American plants stay frozen all the way to the mess sergeants' storehouse on some obscure island half way around the world. A food-packed trailer with its own cooling unit is loaded on a transport as deck cargo and driven off the dock at the receiving end. There are also self-refrigerating storeroom units which are carried in the hold and delivered full of frozen meat at advanced bases. In the march across the stepping-stones of the Pacific, soon after the Seabees arrive, a knockdown prefabricated cold-storage hut with heat-insulated walls is quickly set up and a portable refrigeration unit, which can be run either by its own gasoline engine or by direct or alternating current, is backed against an aperture in the wall. Since these huts are usually well behind the fighting lines, there are other ruggedly built refrigerated trailers which carry foods to the front. Each will hold

8,000 pounds of frozen beef, which is kept at about ten degrees. At the front, the tractor is unhooked and driven off, and the trailer becomes a stationary refrigerator with its own power plant. This does not mean, of course, that all the fighting men are eating fresh-frozen steaks from ice-boxes, but packaged cold is bringing fresh food to more soldiers than ever before in the history of warfare, and is bringing new comfort to scores of special jobs.

"Sweat-boxes," they used to call the ready rooms on aircraft carriers, where pilots assembled in their heavy flying suits to hear final orders before guiding their planes to the cold upper air. Now the rooms are mechanically chilled, and a prelude of discomfort is removed from a job which demands the utmost in alertness. Repairing a bomb sight or a radio set on the hot, sandy desert or a fetid Pacific island was once a job to try a mechanic's soul. Now there is a portable air-conditioned repair hut which telescopes into a package small enough to be shipped by air transport to any remote point, and repairs to delicate instruments are made in half the time with no sweat or dust. On a tropical front, not even the hardiest mechanic can work in the stifling-hot cabin of a grounded plane for more than a few minutes. A mobile cooler and dehumidifier which can be wheeled up beside the plane to deliver cooled air through canvas tubes is now in production. The hottest place in an air field used to be the glass-enclosed control tower, where there is no escape from the sun. This was hell on the personnel, and bad for the weather-recording and radio instruments. Packaged cold came to the rescue. It is also being used to kill moths in the storerooms where fur-lined flying suits are kept. On warships, air conditioning removes powder fumes, helps to maintain the efficiency of gun crews, and protects powder against deterioration in the ships' magazines.

Operating and X-ray rooms in many base hospitals are now comfort-cooled, thereby reducing the danger of infection from sweat and dust, increasing the efficiency of surgeons, and generally contributing to the remarkably low death rate from wounds. Many wounded men are also kept comfortable on the way to the hospital in air-conditioned Pullman-type ambulances.

How it works

Most mechanical air cooling, whether it provides comfort on a battleship or keeps the food fresh in your refrigerator, operates upon the simple principle that when a gas is compressed, heat can be squeezed out of it, and when it expands, it re-absorbs heat. For cooling purposes, a gas is used which becomes a liquid under pressure. Confined in tubes and coils, the gas travels in an endless circle. When it is allowed to evaporate from liquid to gas in the compartment to be cooled, it pulls the heat from the air, and then a compressor driven by a motor squeezes the gas so it can be liquefied again, by removing its load of heat and literally throwing it away. That is why you feel warm air coming out when you put your hand behind your refrigerator.

Another type of refrigerator has no motor or moving parts, but is run by the heat of burning gas, or in its country version, kerosene. This is done by a complicated process invented by two Swedish undergraduates. The flame heats a boiler which contains a solution of ammonia in water. The ammonia gas is evaporated from the water, and draws heat from the food compartment as it expands. Then the heat-laden refrigerant is re-absorbed by the water, its heat is thrown away, and the cycle begins again. Though radically different in operation, it depends, like all mechanical cooling, on the natural law that an expanding gas uses up heat.

This behavior of gas has long been known to every schoolboy. Anyone who has stood in the breeze in a wet bathing suit has felt the cooling effect of evaporation. A liquid cannot change to a gas without using up heat in the process, and in this case, your normal body heat loss is accelerated. If alcohol, which has a lower boiling point and is therefore a more efficient refrigerant, is placed on your skin, it evaporates more rapidly and makes you much colder. The refrigerants used in mechanical air cooling boil at temperatures far below zero, so when they evaporate they absorb the maximum amount of heat for their volume.

Allied soldiers in North Africa used an ingenious application of this principle when someone who remembered his physics slowly poured a cup of gasoline over a superheated bottle of beer and found that the evaporation cooled it. If in some way he had reclaimed the gasoline vapor, condensed it and used it over again, he would have had a crude refrigeration cycle something like the system which operates your refrigerator and keeps the Bijou cool in August.

Carrier started it

Attempts were made to harness the refrigeration cycle long before the turn of the century, but it was not until 1911 that manufacturers obtained adequate data for controlling the cycle in cooling things and people. This was presented in a chart drawn up by Willis H. Carrier, who is known as the "father of air conditioning," and who is now dean of the corporation which bears his name. Mr. Carrier, a New York State farm boy who had gone to Cornell with $5.00 and worked his way to a degree, first faced the complexities of air conditioning in 1902 when his employers, the Buffalo Forge Company, sent him as troubleshooter to a Brooklyn lithographing plant in which the firm had installed ventilating machinery. There was nothing the matter with this equipment, but the air was so moist in summer that the size of printing paper was affected between successive color runs, so that the colors did not register properly. Carrier found a way of drying the incoming air by cooling it, since cool air can hold less moisture than warm air. But there was no reliable guide to the relationships between temperature and humidity, and after years of figuring and experimentation, Carrier perfected such a guide, which is known as the Rational Psychrometric Formulæ. Carrier showed how those obstinate beasts, temperature and humidity, could best be harnessed together to pull the load of air comfort. That was the beginning of today's great weather-to-order industry.

In the first two decades of its career, this guide to artificial weather enabled the South to simulate the favorable climate of southern New England in new cotton-textile mills built near the source of supply. This pointed the way to further freedom from local weather in seeking convenient sites for industrial plants. Air conditioning became a cornerstone in the manufacture of rayon, a process especially sensitive to atmosphere, and it was widely adopted in printing shops, the making of explosives, and other operations in which prescribed temperature, humidity and cleanliness paid big dividends. This early factory air conditioning was done for the improvement of the product, not for the comfort of the workers, but the fortunate few who worked in these plants forgot their dread of sultry summer, and employers found that they got more work done. Soon motion picture houses, which often closed down in the hot months, found that cooled theatres put their business on a twelve-month basis, and many a mediocre mime packed the house because of a gadget in the basement. A new centrifugal refrigerating machine designed by Carrier, and a method of cooling and drying only a part of the air in the theatre at a time, then mixing it with the unconditioned air, helped to make the air conditioning of assembly places safer and cheaper. Hotels, department stores, restaurants and railroads began to follow suit.

Meanwhile, the mechanical refrigerator was rapidly displacing the iceman. In this field, as in comfort cooling, the gases used in the cooling cycle were being rapidly brought into more intimate contact with people who did not understand their dangers as did factory maintenance men. For all the gases which were economical to use were either toxic, inflammable, or both, and had caused a number of fires and fatal accidents. If refrigeration and air conditioning were to fill all the needs which were crying for them, there would have to be a safe gas for the purpose.

Midgley's rabbit

The answer came, swiftly and brilliantly, when Thomas Midgley, Jr.—the discoverer of tetra-ethyl lead to reduce engine-knocking—reached into his hat and produced the first Freon. That great stimulator, Charles F. Kettering, phoned Midgley at his Dayton laboratory and told him what was needed. Armed with a rough idea of the sort of gas required, Midgley and his assistants did a sleuthing job in their chemical library, and after three days came up with a compound whose right name is "dichloro-difluoro-methane." Midgley dispelled all doubt as to the safety of this gas when at a conclave of chemists he inhaled a lungful of it, and then blew out a candle with it, proving dramatically that it was non-toxic and non-inflammable. Soon Drs. M. A. Youker and H. W. Daudt of the du Pont company found a way of making the rare and complex gas cheaply in large quantities from chemicals derived mainly from coal, from salt, and from fluor spar which is mined in Kentucky and Illinois.

That was about 1931. Since then, Freon, in its various forms, has been revolutionizing the whole vast and ramified business of pumping the heat out of air. It is not only safe; in many fields its superior properties as a refrigerant have played an important part in reducing the size and weight of the machinery. In World War I, portable devices to cool food and men would have been prohibitively heavy, and the dangerous gases would have made them a menace anywhere within bombing range. Freon is largely responsible for taking packaged cold to the armed forces ashore and afloat, which is one reason why there is a shortage of the gas for domestic refrigerators. The other reason is that

Freon turned out to be just the thing for the insecticide "bombs" used on tropical fronts. When released from a hand-size metal container, the harmless gas acts as a vehicle for the insect poison.

On all naval vessels air conditioning is desirable, but on a submarine it is imperative. The new gas now makes possible a supply of fresh, cool air to overcome the heat from men and machinery, a great addition to comfort when a sub surfaces in the South Pacific on a hot day. The crews of the new submarines can even smoke, a thing unheard of in other days when the precious air supply was carefully guarded against fouling.

The newest development in refrigerants, Freon 22, has, pound for pound, forty per cent greater refrigerating effect than Midgley's original Freon, and is especially efficient where extreme cold is needed. For example, the aluminum rivets used in airplane manufacture are softer and easier to head when they are chilled. So they are kept in small pushcarts like those of the ice-cream vendor, in which the new Freon keeps them at the right temperature. After they are inserted and headed, the rivets warm to room temperature and expand slightly, insuring a perfect fit. Controlled cold has also brought about the new technique of "shrink-fitting," in which a metal part to be inserted is chilled to ninety below zero in a special chest and then set in place. It expands as it becomes warm and locks firmly in place.

Sky-high weather

One of the most dramatic uses of artificial weather is in testing airplanes and flying equipment in simulated high-altitude conditions. Once it was necessary to risk skilled pilots and valuable experimental planes in actual flights to the eerie, frigid roof of the world in order to test new equipment. Now any condition of temperature, wind and air pressure can be obtained in big refrigerated chambers at a great saving in time and material.

A big wind tunnel at Wright Field, equipped by the York Corporation, will subject a whole airplane, minus wings, to a gale of 600 miles per hour at a simulated height of 50,000 feet, which means that the temperature is around sixty-seven below. It takes twenty hours and 180,000 gallons of brine to chill the tunnel for a one-hour test. The brine, cooled by Freon in refrigeration units, passes through coils in the tunnel at the rate of 2,500 gallons a minute, driving the temperature down to levels where ordinary lubricating oil becomes thick mush and rubber is as brittle as glass. And there are "stratosphere test chambers" where fliers and equipment are whisked from the warm, dense air of sea level to the thin, bitter atmosphere of 40,000 feet—all in the twelve minutes or so in which a fast plane will make the same ascent. In a chamber of this type, a reservoir of cold is built up for many hours, then the cold is suddenly cut off and the chamber is quickly warmed by electric heaters to normal ground temperature. The fliers in their heated suits take their places, and the cooling coils and air pumps turn on the weather of the upper air. Through such tests of men and equipment, pilots are enabled to fly higher, stay longer at high altitudes and dive faster, with advance information about their reactions and those of their planes.

Other weather-making chambers will "take" equipment as high as 70,000 feet, where atmosphere is so rarefied that a man would literally explode from internal pressure, and where a motor may actually overheat at seventy below zero because the thin air cannot carry the heat away fast enough. In testing the new seventy-five-millimeter airplane cannon, it was actually fired in a stratosphere test chamber at a simulated altitude of 52,000 feet, which is far above the present combat ceiling. And at the Aircraft Engine Research Laboratory at Cleveland is the world's biggest ice-box, where giant airplane engines of 3,000 horsepower or better can be tested. To match the cold produced in this chamber, the iceman would have to bring every day a cake weighing 42,000,000 pounds.

For drugs, foods

Blood plasma depends upon packaged cold to keep it fresh all the way from the donor to the wounded soldier. Penicillin, the new miracle drug, could not be processed without it. The special air used in the newest penicillin plants has about as much relation to ordinary air as a surgeon's scalpel has to an axe. First it is finely filtered, then an electrical precipitator takes out microscopic dust particles, then it is deodorized, washed to secure the right moisture content, and finally sterilized by ultra-violet lamps before it is admitted at a specified temperature to the rooms where the mold is incubated and the processing and drying take place. Controlled temperatures as low as minus 76° F. are used in producing the great life-saver. And precisely controlled air conditioning is equally important in the manufacture of sulfa drugs.

Meanwhile a modern version of the parable of the loaves and fishes is being enacted daily as soldiers take a square of compressed, dehydrated potatoes half the size of a pack of cigarettes, crumble it in water, cook it, and get enough for three men. Or take an egg block no larger than a single egg and produce scrambled eggs for twelve. Man-made cold helps to make this possible. Sub-freezing temperatures, used in the dehydration and compression processes, prevents fat globules, tissues or cells from breaking down, thus preserving the flavor and nutritive quality of the food.

Wartime experience in cold production will affect our future living conditions in many ways. One of the first changes will probably take place in the kitchen, where there will be a quick-freezing unit as well as the regular refrigerator, or possibly a combination of the two. Quick-frozen foods have come to stay. Frozen pastries and restaurant specialties as well as uncooked meats, vegetables and fruits hold their pristine freshness for months. Last year, 800,000,000 pounds of food of eighty-five different kinds were quick-frozen by American industry. Freezing plants built on barges are navigating the TVA's great system of lakes and rivers, preserving prime vegetables and fresh-water fish at their points of origin and transporting them cheaply to market. An airline has announced plans for a postwar "ice-box plane" designed to carry a forty-ton payload of food in bomb-like containers to be loaded like block-busters. Now the way seems ready for the use of quick-freezing in Everyman's kitchen, which means less waste of home garden produce, bulk purchase of foods in season, and a richer diet the year round. New mechanical improvements plus mass production will reduce the cost of the freezing unit, and Freon 22, the new refrigerant, will slice the cost of the power that runs it.

The future

Having proved its worth in war both on materials and men, air conditioning is slated for a tremendous postwar boom. Although its use in public places has attracted wide attention, a high percentage of such buildings are still without it. Factory workers who have known summer comfort will not wish to return to sweat, dust and fatigue. It is reasonable to expect that within a few years virtually all factories, shops, laboratories, trains, hotels, assembly places, department stores, office buildings and new apartment houses will be equipped with controlled weather, with immense dividends in comfort, health and efficiency.

Not all buildings will be conditioned by refrigerant gases traveling through a cycle. There is a sandy material called silica gel which drinks up moisture like blotting paper, and many buildings are now made comfortable by blowing the air through containers of this porous stuff, and then cooling the dried air by water coils. Heat is needed to remove the moisture from the silica gel so as to make the process continuous. In localities where fuel gas is cheap, electricity is expensive, and water is plentiful, this method is providing satisfactory low-cost air conditioning.

Buildings will not necessarily be "twenty degrees cooler inside," for the goal of air conditioning is a reasonable state of comfort, not, as some theatre managers appear to believe, competitive freezing of the customers. The paper icicles which hang on theatre marquees are often an invitation to colds and stiff necks because someone has decided that if a little coolness increases ticket sales, Siberian cold will pack the house. There is no such thing as a standard desirable inside temperature in summer; temperature must be regulated with regard to the heat outside. When we leave a warm house in the winter, we put on our overcoats to compensate for the abrupt change, but we leave sweltering streets for cool theatres with no such protection. So the change must not be too great. When the temperature outside is ninety-five, an inside temperature of eighty degrees is cool enough, say the experts—keeping in mind the important fact that relative humidity and air circulation must also be controlled.

But this statement does not apply equally to all air-conditioned spaces. In a hotel room, apartment or office, where people spend many hours at a time, we can better afford to disregard the outside weather and set our sights on absolute comfort. At the other end of the scale is the drug store or shop where customers spend a few minutes; there the temperature change should be least of all.

The air conditioning of passenger automobiles, tempting as it may seem, is a doubtful matter. If the car's motor runs the refrigerating compressor—the only economical method—the city dweller would get little relief while crawling through traffic. He would get real cooling only at high speeds, when he needs it least. Even if this handicap were overcome, the cost would probably be too great to include air conditioning as standard equipment in the average car. But in busses, with their big pay loads and high mileages, summer cooling will probably be universal.

Tailored-weather homes?

And in the future—perhaps the distant future—lies the goal of weather-as-you-like-it in the average home. Home air conditioning occupies a prominent place in the advertising romancer's swank prospectus of "the house of tomorrow," but in the minds of engineers, manufacturers and informed home-owners, it is a large and wistful "if." Before the war, when such refinements were available, the cost of full air conditioning for a house of seven or eight rooms would have been $2,000, more or less. Obviously, a rich man's luxury.

Mass production of standardized units would cut this price radically, but a number of obstacles stand in the way of this goal. Industry will not embark upon the manufacture of home equipment on a scale big enough to guarantee a low selling price until it feels assured of a market that will justify such a course. But in the South, where summer air conditioning is most needed, the average income is notoriously low, while in large sections of the North, where more home-owners can afford substantial improvements, the days of oppressive heat usually occur within a calendar period of sixty days or so, with many comfortable days intervening. Willis H. Carrier cautiously estimates that if industry can find a market for 20,000 units a year, they might be installed at a price of from $500 to $600. Even if we assume lush postwar prosperity, it is hard to tell how many well-to-do home owners in the temperate zone would prefer a few weeks' comfort to a television set, a new car, a helicopter or a Canadian fishing trip. But the South may not always remain poor. There is some reason for believing that the hot Gulf States will retain their wartime industries, and that a geographical redistribution of income is under way. If this should be true, the indoor weather makers will be among the first to profit by the trend.

The price barrier is not the only one; low cost alone will not put air conditioning in every bungalow. In your kitchen refrigerator, the heat from the condensing coil is carried off by air, but in home-size cooling equipment, water is needed, and there is hardly a large city in the country with a water system that would stand the added load if all its residents decided to air condition their homes. The cost of new reservoirs and water mains to support universal home air conditioning would be astronomical, but even that would not solve the problem. In many parts of the country, there would not be enough water anyway. On Long Island, the underground water level has been lowered to a point where industrial plants are no longer permitted to pump water from the soil unless they pump it back again. When artesian wells were first dug in Dallas, water spurted out under high pressure. With the increase in water use, wells must now be driven to 800 feet, and deeper wells are prohibited because they would bring in sea water from the Gulf.

Engineers foresaw this shortage about ten years ago, and the Carrier Corporation has led the industry in developing evaporative condensers which depend to a large extent upon air, greatly reducing the amount of water needed. This will help, but in view of the tremendous predicted increase in industrial and commercial air conditioning, it can hardly remove this barrier to the general adoption of artificial weather in the home.

This apparently limiting factor may not bar controlled weather from many thousands of high-income homes, for shortages in natural resources are usually felt gradually. Cars by the million will continue to roll merrily for some years, although we know that the days of cheap fuel from petroleum are numbered. Several manufacturers nourish a conviction that mechanical home cooling will be common in another decade or two. New technical discoveries now unthought of may make this possible. Before finally resigning ourselves to the impertinences of the thermometer, we should remember the venerable gentleman who once promised to eat the boiler of the first steamboat that crossed the Atlantic.

Home air conditioning, however, is not a matter of all or nothing.

The well-heeled perfectionist may revel in an atmospheric bath of filtered, sterilized, ionized air automatically delivered throughout his house at the desired temperature and humidity, but ordinary mortals may obtain some degree of comfort at far less expense.

Electrically operated cabinet-type coolers, placed before windows to chill the incoming air, are now used in thousands of individual dwelling rooms and offices, and many of them need no water. Before the war they were sold for around $300, and wider acceptance should be followed by drastic price reduction. A variation of this room cooler, which was first proposed more than a hundred years ago by the Scotch physicist, Clerk Maxwell, and which Westinghouse has been developing recently, is a fascinating gadget which heats as well as cools. All air down to absolute zero (minus 459.6° F.) contains heat, and this cooler, when a button is pressed, reverses its operation, and instead of pumping heat out the window, extracts heat from the outer air and pumps it into the room. While too costly to compete with conventional heating systems, this device may find advocates in mountainous areas where summer mornings are chilly and afternoons are hot.

Other roads to comfort

There are also a number of simple ways of making a house cooler without depending upon the refrigeration cycle or the maintenance man who follows in the wake of all machines. Air does not care how it is cooled, and the insulation of roofs and walls not only saves fuel in the winter, but retards the penetration of solar heat in summer. And there is a new wartime paint which bounces off the infra-red, or heat rays of the sun. It is used in gasoline "tank farms" to serve the same purpose as the heat-reflecting aluminum paint once common, which makes the tanks too conspicuous from the air. Applied to roofs, it may keep postwar houses cooler.

An electric fan mounted before a slatted attic window will pull the hot air out of the house after the sun has gone down, while cool air from outside replaces it. If windows and doors are kept closed the next morning, and if awnings are used, the cooling effect may last well into the day. In the Southwest, or in any hot, dry climate, a "desert cooler," either home-made or bought, is marvelously effective in making a room comfortable. This is a window cabinet containing a row of wide, vertical wicks kept wet by a water tank. A fan outside blows air over the wicks, and the evaporation of the moisture absorbs heat from the room. Like grandmother's kitchen-window food cooler, in which the breeze caused evaporation of moisture from wet cheesecloth, this operates on the same basic principle (cooling by evaporation) as the most complicated and costly air-conditioning machinery. It is of real value only in a dry climate, since high humidity in the surrounding air reduces the rate of evaporation and therefore the cooling effect.

Sunshades built like Venetian blinds can be mounted *outside* the windows to reflect the sun's heat and prevent window panes from radiating heat into the room. This idea, which originated many years ago in the fertile mind of the Swiss architect, LeCorbusier, was used in the construction of the admirable new Ministry of Education and Health at Rio de Janeiro. The entire sunny side of this twenty-two story building is protected by the sunshades, which can be individually adjusted from within. Thinking along similar lines, George Fred Keck, a modern architect of Chicago, has built houses with protruding horizontal plywood shades above the windows, which are fixed with regard to the seasonal declension of the sun, so that sunlight is admitted to the house in winter but barred in summer.

Similar methods for *outdoor* air conditioning in hot cities have been proposed by Prof. Albert E. Parr, director of the American Museum of Natural History. When the sun strikes the typical whitewashed wall of a courtyard garden, heat rays are reflected downward and the courtyard becomes a hot-box. A series of wooden sunshades set at an angle on the wall would reflect the heat rays skyward. Similar devices could be used to protect sidewalks which are too sunny, suggests Prof. Parr, who believes that meteorologists should play a larger part in planning cities to minimize the unpleasant effects of wind, fog and smoke as well as summer heat.

Perhaps in that millennial era when the comfort of the human animal is given priority over real-estate profits, ideas like these will be adopted. They can hardly displace comfort cooling by machinery in buildings where large numbers of people assemble, but by reducing the load of heat to be disposed of, they can make the problem simpler and cheaper.

This is a time of wild prophecy, but one may safely venture the opinion that people are getting pretty tired of the fickle climates Nature has been dispensing these many centuries, and that before they finish with the weather the wraith of Mark Twain will eat that gentleman's celebrated words about it.

CHAPTER FIFTEEN

ON THE FARM

When historians allocate credits for the Allied victory, a large share will go to the amazingly swift development by American industry of the new machines, materials and techniques which launched and maintained the great procession of weapons. These triumphs have been widely publicized. But without food for the men who build the war gear, and food for the men who use it, the B-29, the Sherman tank and the bazooka would be impotent.

Never before has the farmer faced such demands as those imposed on him in the years of World War II. Food for our workers and fighters, food for Britain, food for Russia and food for the liberated nations has been grown and shipped in record-breaking quantities—and the job has been done during a period of labor scarcity never before known in American agriculture. This food-growing program could never have been fulfilled were it not for the great surge of inventiveness on the agricultural front in recent years. New labor-saving machines and methods now used on millions of farms have been as important in fighting the war as the electron tube and high-octane gasoline.

This is not the first war in which farm machines have played an important role. It has been said that McCormick's reaper was the tool that turned the tide for the North in the Civil War, for it released men from the farms to join the fighting forces, maintaining the necessary production of wheat for home consumption and for export. Taking a long view, the National Resources Committee has stated that in the year the Constitution was framed, the surplus food produced by nineteen farmers was barely enough to feed one city person, while in recent years nineteen people on farms have produced enough for fifty-six non-farm people, plus ten living abroad. And Department of Agriculture statisticians have shown that while in 1870 it took half the workers in the country to raise our food, one-fifth of the workers did the job in 1930. The labor needed to raise an acre of wheat or corn has been cut in half in about thirty years.

In recent years, this acceleration has been intensified. As recently as the days of World War I, today's demands could not possibly have been filled with the labor available. It is safe to say that with today's best farm equipment, six men can raise as much grain, forage and livestock as could ten men in 1919, and do it more easily. While only a part of the improvements of wartime industry are of value in peace, most of the new farm machines and methods are permanent contributions destined to exert a profound effect upon the habits and fortunes of all of us, whether we live on farms, in villages, or in the large cities. It would take a large volume merely to introduce the reader to the array of agricultural "weapons" now engaged in the never-ending battle for food, and another volume to attempt an appraisal of their economic and social effects. In this chapter, the writer will confine himself to a series of notes and a few speculations.

Tractor evolution

First on the list of machines which have changed American farm life from a Currier and Ives idyl to a highly mechanized mass-production business is the omnipresent tractor. There are seven times as many farm tractors in use today as there were at the close of World War I, but that figure by no means tells the story. Previous to the middle twenties, the tractor was a slow, lumbering behemoth used only on clumsy tasks involving great acreages. Pulling the combine, it revolutionized wheat farming, all but banished the horse and the mule from the great Midwestern prairies, and incidentally displaced many thousands of workers. But where crops grew in rows, the puffing monster was helpless. There, horses still pulled planters and cultivators.

Then two things happened to the tractor. In 1924, the smaller, all-purpose tractor appeared—a less expensive, easily maneuverable machine that would do the work of the average-size dairy or truck farm—plowing, planting, harvesting, and by means of its power take-off, grinding feed, sawing wood or chopping silage. Then nine years later, someone thought of another improvement: why not put pneumatic tires on tractors? This was a very simple idea, but its effect was greater than that of many far more ingenious inventions. This innovation increased the tractor's speed, softened the jolts on machine and driver, and cut down fuel consumption so that a man could plow an acre with a gallon of gasoline, a saving of ten to twenty per cent over the performance of the steel-shod machine. The tires also liberated the tractor from its parent farm and allowed it to haul trailers of produce to market over surfaced roads from which its steel-wheeled predecessor had been barred. And most important of all, they enabled it to travel to neighboring farms and thus hastened the trend toward farm consolidation which the first big iron horses had set in motion. The more money a farmer invests in machinery, the more work he must get from his machines to justify their purchase, and the more desirable it becomes to buy the farm of a neighbor who cannot afford machinery and therefore cannot compete with him in the economical growing of crops.

This trend has been partly countered by the appearance of even smaller tractors. There is the so-called "midget" five-horsepower tractor for the small farmer. Introduced shortly before the war, these small machines had a rapid sale, and they will play a large part in working the small and medium-sized dairy and truck farms of the future. And there is the one-half horsepower machine so light that two men can lift it, suitable for a two-acre gardener.

The tractor has increased milk production in more ways than one. It enables the farmer to raise forage with fewer man-hours, and it diverts to cows the feed that otherwise would be eaten by horses. When tractors displace horses, farmers may buy more cows to eat the hay and grain thus saved, and the new cows also maintain the supply of domestic fertilizer.

Hay-making machines

The great importance of the tractor in mechanizing the farm lies in the long list of other machines which it has spawned, all of which do more per hour because they are pulled by gasoline or Diesel engines. The hayfield is the scene of one of the greatest recent advances in farm machinery. For centuries, the jobs of hoisting hay onto a cart with a pitchfork and stowing it in a barn have called for hard hand work. Because of the short season and the vagaries of the weather, "haying help" has always been in great demand, and wages are high.

On thousands of farms, new machines now take the place of brawn, and the jobs have been lightened so that boys and older men have taken the places of men of military age. One of the newest and most ingenious of these is the pick-up hay-baler, a tractor-hauled machine handled by one operator, which takes the hay cleanly from the windrow and packs it in small, easily handled bales which take up only one-fifth the barn storage space of loose hay. One of the main reasons for the familiar big red barn is the space needed for hay storage. Every summer, tons of hay are hoisted and packed beneath its roof, and throughout the winter it is pitched down again at great expense in man power. At the rate that farm hay-balers are being adopted, the barns of tomorrow may be low-lying sheds, to the great advantage of everyone except artists.

A number of big manufacturers of farm equipment are making the pick-up balers. One such machine bales the hay in ready-sliced portions like the bread in the grocery stores, thus simplifying the winter feeding chores and preventing waste. Another makes a cylindrical bale in which the hay is wound like a roll of paper, easy to tear off for feeding. Because these new bales are more porous than the old, heavy compact bale, hay may be harvested with a greater percentage of moisture than was once possible. This means a shorter wait between mowing and baling, which speeds up the harvesting process, helps to preserve the nutritive value of the fodder, and lessens the likelihood of crop damage by rain. Some California farmers have equipped their balers with electric lights, so that not even nightfall interferes with speedy harvesting when the weather is right.

Once when hay was stacked in the field, it had to be loaded on the cart, drawn to the stack and unloaded by hand. Equipment sold by a number of firms now telescopes these operations. For instance, there is the "sweep rake," a huge scoop twelve feet wide with teeth several feet long. Pushed by a tractor, it collects the hay quickly in big loads and deposits it on the teeth of a power-operated stacker, which swings it into the air and builds a thirty-foot stack in half the time needed by the older methods.

California, with its great ranches and long growing season, leads the world in mechanized forage production. On the Gill Brothers ranch at Madera, a big covered trailer the size of a freight car is pulled behind a tractor-drawn rake. The machine picks up the hay from the windrow, chops it finely and shoots it into the trailer by means of a blower. When it is full, an empty trailer is hooked on, and a truck rushes the load over the highways to the cattle-feeding yard, where it is automatically stacked, ready to be "processed" into beef.

Another speedy "covered wagon" preserves the substance known as "carotene" in alfalfa, essential to chicken growth. If alfalfa is left in the blazing sun longer than an hour after it is cut, the carotene content is depleted. So farm-machine engineers at Stockton, Cal., built a special alfalfa harvester which cuts the crop, loads it while it is still green, shades it from the sun, and rushes it to the dehydrator in time to preserve its full value.

More and better foods for milch cows have played a leading part in enabling dairy farmers to meet the stupendous wartime goals assigned to them. Since calves do not grow into cows any faster because a war is going on, the new goals could not be met entirely by increasing the herds, but the yields of existing herds have been increased by higher feeding.

Silage, unsurpassed as a food for producing milk, was once made only from chopped corn, but today, grass silage is used extensively by dairy farmers. Grass loses some of its food value when dried into hay. Now the full value is preserved by means of a tractor-drawn machine which cuts the grass, chops it finely into the moving cart, and delivers it to the endless-belt elevator which fills the silo. Blackstrap molasses, pumped from a tank into the silo in the right proportion, ensures the necessary fermentation which the natural sugar of corn provides in ordinary silage. Several other highly nutritive forage crops, among them alfalfa, soy beans and green oats and rye, are converted by the new method into appetizing silage which plays a vital part in swelling milk production.

More silage to make more milk called for more silos, and these familiar cylindrical storage towers use large quantities of wood and metal hoops, or cement, and construction man-hours. Most farmers are tidy traditionalists, and like to store their silage in trim silos, but experiments have partially broken down this prejudice. It has been shown that in many parts of the country, trenches dug in the ground, filled with silage and covered with straw and earth, will keep the valuable milk-producing food in good condition.

Mechanized corn growing

The corn crop, dependent for years upon the government's crop-subsidy largess, has once more come into its own because of wartime demands. The great new corn fields were needed, not only to feed cows and pigs to raise more milk and pork, but for factory conversion into starch, oil, and ethyl alcohol for explosives, textiles and synthetic rubber. New machines and new plant-breeding methods have helped the farmer to meet the demand in spite of the shortage of labor. Once corn was cut and shocked by hand, hauled to the barn, and husked by hand in a tedious operation which extended into the winter. First the corn harvester eliminated one hand operation, then came the mechanical husker, and now the two are combined in a machine which takes two rows at once, picks the corn, runs it between two rollers whose talons gently but firmly remove the husk, and, always on the move, carries the load swiftly to the bin. This harvester can pick and husk 1,000 bushels a day—the work of sixteen men. By speeding the harvest operation, it enables the farmer to turn quickly to other seasonal chores; by outracing early snowfalls, it prevents crop losses, and like all other mechanical crop-gatherers, it lifts from the farmer's wife the burden of cooking for a hungry crew.

Dovetailing neatly into the mechanized system are the strains of disease-resistant hybrid corn developed in recent years by agricultural research men. Planted in rapidly increasing acreages throughout the corn belt, the new corn has not only increased the crop yield in many cases as much as fifty per cent, but because of its habit of upright growth and the fact that its ears appear at a uniform height from the ground, it is especially adapted to mechanical harvesting.

Inventors vs. the sugar beet

The sugar shortage has acted as a tremendous spur to mechanization of the great sugar-beet farms of the Middle and Far West. When the supply of cane sugar from the Philippines was cut off, the Department of Agriculture immediately encouraged the 65,000 sugar-beet growers to increase their planting by some 200,000 acres. Thinning the plants and harvesting the crop have always been two of the worst bottlenecks in beet growing. New machines have been devised to solve both these problems. They have not yet been widely adopted because of metal restrictions, but they have been thoroughly tested.

Young beet plants have always required a lot of thinning because the seeds grow in clusters protected by a hard, woody covering. These hulls were planted whole, with the result that the young plants were too close together for proper growth. Then Roy Bainer of the U. S. Agricultural Experiment Station at Davis, Cal., perfected a device which cracked the hulls between a disk and a moving belt, so that the seeds could be planted singly. Thousands of acres were planted with the single seeds, enabling one man with a thinning hoe to cover as much ground as three men could cover when the whole hull was planted.

But there was still a "bug" in the process. The single seeds were not uniform in shape, and sometimes the spacing was uneven when they were fed from the hoppers of the mechanical planters. Along came another agricultural inventor, M. J. Buschlen, technical expert of a midwestern growers' and processors' group. He worked out a mechanical method for coating each seed with a harmless plastic material which hardened, thus producing uniform white pills which would flow smoothly from the planting machine. Soon after planting, moisture melts the material and frees the seed. Last year, hundreds of acres in various parts of the country were planted experimentally with these pills.

To break the other bottleneck—the labor of harvesting the beets—mechanical harvesters have been developed by a number of government experiment stations, agricultural colleges, implement manufacturers and individual beet-growers. There are several steps involved in harvesting beets. The tops must be cut off, the beets must be lifted from the soil and freed of clinging dirt, and they must be loaded on trucks for the processing plant. Every year this job has required a vast army of "stoop" labor, for by hand methods one man can cover no more than a quarter of an acre a day. Several new beet combines have been used which perform all these jobs at once, and enable three operators to harvest an acre of sugar beets in less than an hour. A new tractor-drawn beet harvester developed by the Department of Agriculture in cooperation with the University of California tops, digs, and cleans the beets and loads them by an endless-belt device into trucks which travel alongside. A Diesel-powered harvester invented by the Brothers Zuckerman, big beet growers of Stockton, Cal., has a series of "sticker knives" on revolving wheels which stab the beets in the top and carry them out of the loosened soil as they rotate. In five minutes a five-ton truck is loaded, ready for a quick trip to the processing plant. A number of other harvesters have been devised. These machines not only save labor, they save sugar, for with every hour's delay between the ground and the factory, there is a falling-off of sugar content in the beet.

The increased beet planting also helps to boom milk and beef production, for the tops, and the pulp that remains after the sugar is cooked out, are used as cattle feed. At one processing plant, the beet pulp is loaded onto trains with a power shovel and shipped to ranches for quick conversion into quality beef. This may be a preview of assembly-line food-production methods of tomorrow.

While resumption of imports of cane sugar may ease the demand, and cane sugar also is being produced more and more by machinery, this is not likely to halt the trend toward complete mechanization of the sugar-beet industry. Power-driven machines will produce the sugar, all the way from the seed to the bin.

Speed-up in planting

The national tomato crop has boomed during the war years, and here again, a new machine has played a leading role. For years one of the greatest challenges to the implement manufacturer was the slow, back-breaking job of transplanting such vegetables as tomatoes, celery, cabbages, cauliflower, strawberries and lettuce. Now even this delicate task has been mechanized by the engineers of the farm implement manufacturers. One transplanting machine used on truck farms throughout the Eastern states has hoppers for fertilizer and plants and a tank for water. It digs a trench, deposits fertilizer, covers it with earth, inserts the plant, waters it, and presses the earth around it, all automatically. Since it is not human, it cannot pick up the plants correctly from the hopper. So it has seats for two men, who select the plants and place them as needed in a rubber-lined "mechanical hand." The flexible hand, mounted on a revolving endless chain, carries the plant down to the hole prepared for it, carefully inserts it, and releases its grip.

This versatile machine has even been used by State Conservation Departments to plant tree seedlings in the shelter-belt area. There is another machine which was devised especially to meet the government goal of 2,500,000,000 trees in the Great Plains. Manned by three men, it digs a trench, plants a tree, and packs the earth around it at the rate of 8,000 saplings a day.

The significance of machines like these extend far beyond the striking results already obtained with certain crops. They indicate that there are few if any farm processes which cannot be fitted to the Procrustean bed of mechanized production. If the corn cannot be picked by a harvester, rebuild the corn. If seeds cannot be mechanically sown, change the seed. Some crop lands now worked, some plants now grown, some farmers now farming will refuse to be absorbed in the great new outdoor industry of food manufacture. If we may judge the future of these recalcitrants by similar examples in non-farm industries, they will cease to be effective food-production units and become relics of an era that has passed.

Circumventing the weather

Research workers are even challenging the stern dominance of temperature and rainfall, and are perfecting new methods which prevent crop losses due to these unpredictables. The "variable-depth cotton planter," invented by John Randolph of the U. S. Bureau of Agricultural Chemistry and Engineering, makes sure that enough seeds for a good crop will come up, regardless of the weather. The planting shoe rises and falls in a wavy line, so that seeds are planted at various depths. If a late frost kills the seeds near the surface, it spares the deep ones, and if early spring rains drown the deep ones, the ones in shallow soil come up and save the crop.

Another new device, the moisture meter, developed at the Michigan State College Experiment Station, is being used on Western irrigated farms as an accurate means of determining when crops need more water. Pieces of plaster of paris, their ends connected with wires to form a part of an electrical circuit, are buried permanently at depths of one, two and three feet. The porous plaster is always as damp as the soil around it, and the damper it is, the less the resistance to the current. By means of a light, portable meter which has a dial and an earphone, one may "listen" to the moisture content of the soil, and tell when to open the irrigation spigot. By this method, crops get the exact amount of moisture they need, and no water is wasted.

To outwit the late spring frosts which wreak heavy damage upon crops, particularly in the truck-farming regions of the Eastern seaboard, Doctors Wade and Poole of the U. S. Vegetable Breeding Laboratory at Charleston, S. C., are producing strains of vegetables which will survive these untimely cold snaps. Using equipment of their own design, they test various strains for resistance to cold, and they treat sensitive plants with progressively lower temperatures to toughen them for colder climates.

A motor-driven, bottomless refrigerator is suspended from a crane at the side of a truck. The ice-box is lowered over seedlings in the experimental field, and they are given an artificial frost for half an hour to test their hardiness. By this means, a number of varieties of cold-resistant cabbages have been found, and work is under way to produce melons which can be planted and marketed earlier than the usual Southern varieties. Using the slower method of testing by natural frosts, Dr. Wade has toughened strains of peas so that in some years it has been possible to plant early enough to raise two crops in one season. By similar methods, Doctors Dickson and Hoppe of the Wisconsin Experiment Station have developed strains of field corn which will sprout on spring days so cold that ordinary corn is discouraged.

Foolish plowman?

Experimental work in preparing land for planting has kept pace with the general advance. About five years ago, soil-conservation experts became interested in what has been called "rubbish farming," in which the field is not plowed for planting, but scarified with a disk harrow or a specially designed instrument just enough to receive the seed. The blanket of crop residue left from the previous year protects the soil from wind erosion, and also assists in the conservation of moisture. A number of tracts in Midwestern states were planted in this manner, and the idea drew favorable comment from experts.

Last year this plan assumed the status of a crusade against the moldboard plow when the book, *Plowman's Folly*, by Edward H. Faulkner, attracted national attention. As a result of several years of plowless experimental growing on his farm near Elyria, Ohio, Mr. Faulkner concludes that there is no sound reason for plowing, that farmers plow because their fathers did and because plowing is a neat way of disposing of last year's stubble and rubbish. Actually, the plow is the worst curse of the land, he writes, and is the chief cause of wind and water erosion and lowered soil vitality. Plowing destroys the ground's system of capillary attraction by which underground water is drawn up to nourish plants, he states. And when plant residue on the surface is plowed under, it forms a subterranean "blotter" which sucks up moisture and prevents it from reaching plant roots.

In support of his theories, Faulkner tells how he raised a bumper crop of tomatoes by simply laying the plants on the surface of the unplowed field and throwing a little soil over the roots, and how he raised five pickings of beans on his unplowed land while his orthodox neighbors raised only one or two.

Since the moldboard plow has long been regarded as the chief pillar of successful farming, and generations of farmers have been urged to "plow deep," Mr. Faulkner has his critics. One of them, Prof. Emil Truog, soil authority of the Wisconsin College of Agriculture, vigorously attacks Mr. Faulkner's claims and tells of controlled experiments at the Wisconsin station in which plowed land yielded far more corn and wheat than scarified land. Other experts hail Faulkner as a prophet of a new agricultural era. It is too early to predict the ultimate fate of the plow, but it is obvious that if "row crops" are to be raised on ground covered with vegetable debris, many of the time-saving machines now used for planting and cultivation will have to be scrapped or radically altered.

Weeding by fire

There have been a number of new experimental attacks on the weed menace. One of the most interesting is the "flame weeder," the invention of Captain Price McLemore, cotton planter of Montgomery, Ala. McLemore, an Army Reserve officer, saw a military flame-thrower and built a machine which uses the same principle to kill the weed grass which for years was the bane of his existence. Mounted on a tractor, the flame-weeder straddles two cotton rows. Tanks of fuel oil feed jets of flame, driven by compressed air, which strike the ground two inches from the cotton stalks, subjecting both grass and cotton to a heat of 2,200 degrees for a small fraction of a second. A few hours later the grass turns brown and dies to the roots, while the cotton plants, with their sturdier stalks, are not injured. This weeder does not tear up plant roots like a standard cultivator, which sometimes does more damage than good, and it can be used on ground too wet for conventional cultivation. Captain McLemore has also used it on corn, tobacco, sugar-cane and sorghum crops. Department of Agriculture experts have been conducting exhaustive tests, and the flame-weeder may join the long procession of machines that raise food faster and cheaper.

Farmers in the Imperial Valley of California have been trying out a machine to electrocute the weed seeds in the soil before the crop is planted. For years, networks of electric cables have been used to kill weed seeds in soil used by greenhouses, but this new tractor-drawn implement is devised to "sterilize" entire fields. Twenty-four electrodes spaced over a strip of seven feet make contact with the soil. With an output of 16,000 volts, the machine is designed not only to kill weed seeds, but insects and fungus pests, as it is driven over the prepared ground. Another experimental approach is that of Burr Elliott of the State of Washington, who invented a machine which uses steam to rid the soil of weed seeds before planting. On a Diesel-powered disk harrow Elliott mounted an oil-burning steam boiler. The machine chugs across the field, pulverizes the earth and shoots in superheated steam.

The killing of insects stored in grain by the use of electron tubes is a project which may increase effective food production by hundreds of millions of dollars annually. In this process, which the Department of Agriculture believes will be used widely as the equipment is available, tubes which broadcast high-frequency, heat-producing radio waves—the same tubes used for short-wave therapy and plywood bonding—are mounted over moving conveyor belts which carry the grain. Exposure to heat for thirty seconds or less is sufficient to sterilize the grain. While this method will probably be used in grain warehouses and by food-processing firms instead of on the farm itself, it is another step toward the common goal—more food from fewer acres.

Reiter's revolt

Another invention which may end an onerous chore and save man-hours is the mechanical stone-picker. Field stones have always been a curse on Northeastern farms. They break planting tools and mower knives and take up room which might accommodate plants or moisture. For centuries, farmers have strained their backs picking them by hand and hauling them from the field before planting. Twenty years ago, Otis F. Reiter, a Maryland farm boy, straightened his aching torso and told his brothers he was going to build a machine to do the job. Now he has done it. His tractor-drawn stone-picker, which looks like a military tank, has a revolving cylinder set with steel fingers which pick up all surface stones from thumb-size to bucket-size and toss them into the hopper. When it is full, the two-ton load is hauled to a dump and the bottom falls open like that of a coal car. Tests of the machine at Pennsylvania State College show promise.

There are many new food processing and storage methods designed to save labor and prevent spoilage of food on the way to the consumer. One example is the explosive walnut cracker invented at the California College of Agriculture. A rotary saw cuts a hole in each nut through which a mixture of acetylene and oxygen is injected, then heat acts upon the gas and the shell bursts open, dropping the clean nut meats into a container. Another example is a "flame" method for the fast peeling of citrus fruits in plants where the juice is canned. The oranges or grapefruit pass through a gas-fed flame where they are subjected to intense heat for a few seconds. This chars the peel, which is quickly removed by a powerful spray of water.

A new method of preserving apples and pears at normal temperatures has been developed at Cambridge University and tested and approved by Dr. R. M. Smock of Cornell. Dr. Smock explains that stored apples are living things, and that we can retard their aging by slowing down their rate of living. This is done by giving them less air to breathe; that is, by storing them in an airtight bin, with the air intake scientifically regulated. By this method, Dr. Smock has kept McIntosh apples in good condition for two years without refrigeration.

"Animal factories" on trial

There are bound to be many changes in future food demands, and some of them will naturally arouse the bitter enmity of farm groups whose oxen are gored. In the United States, as well as in other countries, there have always been millions of families whose incomes have not allowed them a diet which health authorities consider adequate. It is a trite but frequently ignored fact that diseases flourish lushly among undernourished people and quickly menace all the people; that the bell, as Hemingway reminds us, tolls for thee. It follows obviously that in any respectable and intelligent society, the nutrition needs of all the people should be the primary consideration in an organization of food production methods.

Dairy products and meats are among the items which a large segment of the American people have never been able to buy in sufficient quantities. Wartime shortages have extended this dearth to all the people, and have stimulated the sale and experimental development of other foods which are cheaper and more plentiful and of equal nutritive value. The question has naturally arisen: is it necessary to use the cow and the steer as factories for the processing of vegetable raw materials into nutritive fats and proteins?

It has been conclusively proved that margarine, made by churning a pure vegetable oil—usually cottonseed or soybean—with skimmed milk, salt and other minor ingredients, and fortifying it with Vitamin A, is the nutritive equivalent of butter. That it can be produced more efficiently than butter is demonstrated by the fact that it sells for about half the price. Pressure brought upon Congress and state legislatures by dairymen's lobbies has been so effective that margarine has been virtually barred from the shelves of two-thirds of the country's grocery stores. Efforts by consumers' groups and margarine manufacturers to break down these barriers have not yet succeeded, but during the war the vegetable table spread has found many new friends. Meanwhile, a number of large butter processors have added margarine to their products, and Midwestern growers of soybeans are looking to their interests. It seems reasonable to expect that the laws restricting margarine will eventually be stricken from the books, and that it will be available to everyone. Many people will still prefer butter. But even if, as the dairymen fear, margarine cuts into their market, the first principle of food production will remain undimmed: the welfare of all the people must be the first consideration.

"Synthetic meat"

Meanwhile, the meat shortage has aroused interest in all manner of vegetable proteins. Anheuser-Busch, the St. Louis brewing firm, caused a sensation two years ago when at a demonstration meal they served a "synthetic meat loaf" made from a special yeast developed in its laboratories. It was appetizing, was a rich source of Vitamin B and had twice the protein value of meat, and the cost of the protein was said to be one-fifth that of protein contained in meat. Soups, muffins, and other foods were served made from various kinds of yeast. In 1940, A. C. Thaysen of England raised a new food yeast which the British government has been manufacturing as a supplement to war diets. Later, Dr. and Mrs. Carl Lindegren, St. Louis geneticists, bred many new kinds of yeast by cross-fertilization and laid the foundation for the brewing company's venture. A mixture of molasses, water, ammonia and yeast is poured in a vat and air is driven through it. The tiny yeast plants, fed by the sugar, multiply rapidly, and great quantities of the final product, a light brown powder, are turned out in a short time. The Government has been buying the "synthetic meat" in bulk, and Anheuser-Busch is making postwar plans.

Research at the University of Illinois, Harvard, Yale and other institutions has shown that there are a number of inexpensive vegetable foods which will take the place of meat in supplying the necessary proteins to the human organism. In a basic approach to the problem, Prof. William C. Rose of the University of Illinois worked with twelve student volunteers, who for eight months "drank their steaks" in the form of amino acids contained in a lemon-flavored liquid. These acids, over twenty in number, are the building blocks of proteins, and the purpose of the work was to determine which acids were essential to human health.

Dr. H. H. Mitchell, protein expert of the same university, reports that corn germ—the small yellow nub in the kernel of corn—has the protein value of beef, and the National Research Council has advised its widespread use. A soup containing corn germ has been placed on the market. The nub contains so much oil that it spoils quickly, but if the oil is extracted, a white, protein-rich powder remains which keeps well and can be mixed with other foods to furnish a meat substitute.

Nutrition tests and analyses of meat substitutes, conducted at Harvard and Yale, have resulted in devaluating the beefsteak and promoting the consumption of protein-rich vegetables, particularly the soybean. The virtues of this bean when ground and added to other foods are well known. Food experts also advise that soybean sprouts, rich in Vitamins B and C, can be easily grown in a jar in the kitchen.

Soybeans are one of the most valuable feeding crops of the dairy farmer, and millions of additional acres have been planted since Pearl Harbor. Plowed back into the soil, soybeans provide much needed nitrogen, and when fed to cattle, they supply the proteins indispensable to peak milk production. But there is also a growing industrial demand for soybeans for use in plastics, paints and insecticides. It is a bean of great value. Is it economic to route it through a bovine processing plant?

Even if that question is answered in the negative, our food habits are not likely to change overnight. Habit, taste and prejudice are of tremendous importance in food selection. Few consumers are likely to scorn the time-honored and appetizing sirloin steak at the behest of scientists, no matter how distinguished. But big corporations are interested in these protein foods, and their advertising men are doubtless ready with catchy names and an ample stable of radio cowboys and super wizards.

New proteins have been developed to feed cattle as well as humans. If there should be a shortage of protein feed, synthetic urea, an inexpensive powder derived from coal, may be mixed with the cattle food. Feeding tests at experiment stations in Wisconsin, Illinois and Massachusetts show that animals with multiple stomachs, like the cow, convert the urea to protein, and the Association of American Feed Control Officials has stated that this chemical can pinch-hit for one-third of all the crude protein used in feed for cattle and sheep. And at the University of New Hampshire, tests have been made in feeding to cattle yeast protein derived from sawdust and other wood waste. Chemicals are added to the wood, and it is "cooked" to convert the cellulose into sugar. The sugar feeds yeast organisms, and the result is a brown powder which animals find palatable. Experts of the Northeastern Wood Utilization Council, which is interested in the project, envision small wood-conversion plants conveniently located to supply cheap protein feed to New England dairy farmers.

Frozen food "banks"

The community frozen-food locker plant and the home quick-freezer, both developments scheduled for rapid growth after the war, will greatly increase the self-sufficiency of the farm family. Many years ago, Clarence Birdseye made a fortune by commercially exploiting the fact that foods quickly frozen at temperatures of zero or below retain their original structure, flavor and nutritive value. Birdseye's frozen foods, sold in retail stores throughout the land, paved the way for the locker plant. The locker plant is a large building containing from 100 to 1,000 compartments which are rented to individual customers for the freezing and storing of their meats, fish, vegetables and fruits. Many of the plants will slaughter, wrap in meal-size units and quick-freeze an entire animal, for a charge of perhaps one and a half cents a pound, and when the housewife goes shopping, she draws food from her locker as she would draw money from the bank. Lockers of six cubic feet have been renting for about $10 a year.

There are about 5,600 locker plants in the country which serve as "food banks" for more than two million families. Some of them are conducted as a sideline by big packing firms, others by farm cooperative stores, and there are small village locker plants equipped to serve a hundred families or less. Many non-farm families rent lockers and buy and store meats, fish and fruits in quantity at times when there is a market glut and prices are low, but of course the locker offers greater economies to the family which raises the food.

Because locker plants save tin cans and freight car space, some expansion has been allowed by the WPB during war time, but not nearly enough to satisfy the demand. Millions of families are on the waiting list for lockers, and the number of plants is expected to double as soon as construction materials and refrigeration equipment are available.

Home freezers

The home freezer offers even greater convenience, and during the years of rationing it has been a godsend to its owners. To the farmer who kills a pig and a steer for home consumption every fall, and has the usual vegetable garden and fruit trees, the freezer may be a cornucopia of fresh food throughout the year, with nothing out of season. It is the grocery store's low-temperature cabinet brought into the home, from which the housewife can quickly produce a wide variety of fresh edibles for unexpected guests or hired men.

There will be a stampede for home freezers as soon as materials are released for their manufacture. They would be of greatest value in increasing the living standards of farm families of low and medium income, and of families whose breadwinners have non-farm jobs and depend upon a few acres to supplement their wages. Whether the freezer reaches this stratum of greatest need, or is restricted to the more prosperous farmers, villagers and suburbanites, will depend upon its postwar price and the cost of electricity. Before the war, medium-size home freezers were selling for about $300, and the monthly addition to the electricity bill ran from $2.00 to $3.00, depending upon local rates. With volume production, freezer prices will of course be reduced, but the cost of freezing the produce of a hundred families will always be lower than the cost of freezing the same amount of food in a hundred small plants. Even after considering the convenience of the home supply source, most farm families in areas where locker plants are easily accessible will do some comparative figuring before making an investment.

Fish in your backyard

"Fish farming" is another profitable and promising method for raising rural living standards, particularly in the South, where ice almost never forms on water. Encouraged by the Soil Conservation Service and the Fish and Wildlife Service, fish ponds are being built in all states of the Union. Farmers by the thousand in Alabama, Georgia and South Carolina have built small, shallow ponds which are fed by streams, by land drainage, or by the overflow from artesian wells. These ponds are stocked with fingerlings of bass, bream and other good eating fish, which are obtained free upon application from State Conservation Divisions.

There is nothing new about the maintenance of private fish preserves by farmers and sportsmen, but there is a new technique perfected by H. S. Swingle and E. V. Smith of the Alabama Agricultural Experiment Station at Auburn which has tremendously increased the yield of fish and has greatly stimulated the construction of such ponds. Adapting a practice used in hatcheries, Swingle and Smith scattered commercial fertilizer in the ponds in much the same manner that fields are fertilized.

As they explain the system: "Pond-fish have been found to feed mainly on microscopic water animals, water insects, and small fish; most of these small animals, in turn, use microscopic plants either directly or indirectly for food. These plants are . . . present in most waters but the number is small . . . When the pond is fertilized, however, these plants grow and multiply rapidly . . . Thus the reasons for fertilizing a pond and a pasture are essentially the same; both are fertilized to produce more plants and to produce more animals, but in one case the animals are fish and in the other they are cattle . . ."

Unfertilized ponds, they report, may support a population of from forty to 200 pounds of fish per acre of water, but with proper fertilization the fish in many ponds in Alabama have increased to between 500 and 600 pounds per acre—over twice as much as the weight of beef or other meat which could be produced from crops if the acre were drained and devoted to planting. The writer has corresponded with a number of Alabama fish farmers, who state that these results are not merely experimental; that they work out in practice. By hook-and-line fishing, about half the fish in the pond can be caught every year.

Pond owners also report that before they used fertilizer they caught only small and undernourished fish, but now take plenty of bass weighing from two to five pounds. Two factors bring this about. Fertilization indirectly increases the supply of provender for the fish, and the tiny aquatic plants encouraged by fertilization shade the large weeds and causes them to die. The weeds have served as a refuge for the small fish, and when the weeds disappear, the carnivorous fish are able to reduce their excessive number. As added dividends, elimination of weeds makes for more enjoyable fishing and better mosquito control.

The ponds vary in size from one to thirty acres, many of the larger ones being stocked and maintained by clubs of sportsmen in the cities and towns. Most state laws forbid the marketing of game fish, so fishing is strictly a pond-to-table operation. The cost of the fertilizer—the chief cost, once the pond is built—may run from $15.00 to $20.00 per acre annually, and with a yield of 250 pounds per year, this would mean a fertilizer cost of no more than eight cents a pound for the fish. With a little figuring, one can see that in return for the investment, a family of four or five might receive the equivalent of a fish dinner a week throughout the year, with the sport of fishing thrown in for good measure. And there is no storage problem. The pond is the icebox, and the fish are so fresh they quiver on the platter.

Conclusions

All signs indicate that small-scale, general purpose farming is doomed, that farming as a "way of life" is going the way of the surrey with the fringe on the top. Some small farms, like some small factories, will continue to operate because they pick up the crumbs ignored by the titans, but most of them will disappear as effective economic units. Successful farming today requires such a large investment in expensive machinery and equipment that operation becomes profitable only on large and easily cultivated areas. Operators of the great farms, which are really streamlined food factories, can raise produce of all kinds at costs which enable them to outsell their partially mechanized, small-acreage competitors. Summering in a rural New England village recently, the writer walked past a dozen farms to the general store, to buy vegetables from California and cheese from Wisconsin.

This trend has been evident for years. Great numbers of farms ranging from twenty to a hundred acres have been abandoned or added to other farms, while the "food factories" covering a thousand acres or more have rapidly increased in number. Labor-saving machines and techniques like those described above are bound to accelerate the movement.

Meanwhile there has been a substantial increase in the number of family-owned and operated small plots which cut the living costs of people whose main income is derived from non-farm jobs. All methods by which families may obtain food for their tables from small plots of land with little capital investment are bound to be of increasing importance in the years that lie ahead of us. The ownership of such plots by factory workers has been long advocated by leading industrialists, notably Henry Ford. The wider distribution of factories throughout the country, brought about by the war, has brought a higher percentage of workers nearer to the land, and many of these new plants will continue to operate when the war is over. Further decentralization, assisted by new rural power sources such as those of the TVA, may place within reach of millions of families once totally dependent on the weekly pay check a much needed hedge against unemployment.

As great acreages of farm land unsuitable for mechanized food growing are gradually abandoned, the problem of how best to utilize these submarginal tracts will arise. Many of these areas will be reforested, and many will be turned into summer playgrounds. As mechanization in all occupations is intensified, the greater will be the need of workers for relaxing outdoor vacations. Many farms now being worked would add more to national production if turned into golf courses. As these lands pass out of agricultural use, huge new areas should be added to the public domain to preserve their attractions for the many.

In passing, it is only fair to warn the reader that not all machines which appear to save labor succeed in their purpose. A fable told by an engineer of a big industrial plant illustrates the point. A proud owner, he said, showed a guest through a factory where the final goal of mechanization had been achieved—all human labor had been eliminated. Raw materials entered at one end, and were pounced upon by a vast array of superhuman machines which automatically stamped, hammered, welded, assembled and painted, turning out the final glittering product without the use of human hands. But, strangely enough, the plant was teeming with workmen. They, explained the owner, were maintenance men.

Some of the new farm machines, as well as some of the industrial machines described in this book, will be defeated by their own complexities, and men will step in to take their places. But other engineers will design better machines. Motor power will continue to displace man power. As a general rule, it seems logical to assume that labor-saving machines save labor. Increased technological unemployment among farm workers seems inevitable. In the report *Technology on the Farm*, published by the Department of Agriculture in 1940, it was estimated that if current trends continued, from 350,000 to 500,000 farm workers would be displaced in the next decade. The war has deferred this displacement, but there is more reason than ever to assume that this trend will continue after its close.

Once the farm was a cushion which absorbed much of the shock of industrial unemployment. Now the movement has been reversed, and landless farmers will seek jobs in factories. And the newly tooled factories will be making more goods with fewer men. It is true that the new machines used in our present industries have created new jobs of manufacture, repair and maintenance, but if they created as many jobs as they destroy, they would not pay and would not be used.

The only solution is the use of displaced man power to further improve the standard of living. Paradoxical as it may sound, if all the people are to receive the bare necessities of life, today's luxuries must also become necessities. Many industries, among them television, improved transportation, new highways and housing will absorb large groups of surplus workers. After they are saturated, new industries must be created to fill new needs and desires. Such projects as forest culture, mosquito control and roadside beautification must be fully financed and fully staffed. Tearing down and burning all the roadside billboards in the country would provide valuable work for many men. Since consumers should learn to read the bills that they eventually pay, a publicly controlled museum of science and technology, with lectures and motion pictures, should be established in every sizable city in the country. The public education system should be greatly expanded. Civic theatres and symphony orchestras should be the rule rather than the exception. To him who asks: "Can we afford all this?" the answer is: "Can we afford poverty, disease, depressions, mass uprisings and world wars?"

The problems created by the new technology are not American; they are global, and upon their solution depends the peace of the world. Men have fashioned many new tools of which they are justifiably proud. These gadgets will glitter marvelously in the years to come, but without honest and intelligent planning to use them for the benefit of all mankind, they will not be worth the powder which will most certainly blow them to bits.

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